PIER

PUEY UNGPHAKORN INSTITUTE FOR ECONOMIC RESEARCH

# Revisiting Thailand's Monetary Policy Model for an Integrated Policy Analysis

by

Pongpitch Amatyakul, Tosapol Apaitan, Savaphol Hiruntiaranakul, Nuwat Nookhwun

September 2021

Discussion Paper

No. 164

# Revisiting Thailand's Monetary Policy Model for an Integrated Policy Analysis*

Pongpitch Amatyakul, Tosapol Apaitan,

Savaphol Hiruntiaranakul[†], Nuwat Nookhwun

27 September 2021

**Abstract**

The constraints facing conventional monetary policy during the recent COVID-19 pandemic accelerate the central banks' use of integrated policy, using multiple tools to fulfill their macroeconomic objectives. This paper, therefore, aims to improve Thailand's monetary policy model for conducting policy analyses involving multiple tools. We embed macro-financial linkages into our model, which facilitate the identification of various policy tools at the central bank's disposal. The model also features multiple sources of nonlinearity, including an effective lower bound (ELB) constraint, to better capture economic dynamics during crises. We allow for a joint calibration of several tools, including conventional interest rate policy, foreign exchange (FX) intervention, macroprudential regulations and financial measures. Last, given a greater emphasis on financial stability, we attempt to measure macro-financial tail risks, which permit an analysis of policy trade-offs in addressing risks to financial stability. We show three applications of our model to shed light on potential gains from policy complementarity during the aftermath of COVID-19 pandemic: first, assessing the role of financial measures and FX intervention in supporting economic recovery; second, evaluating the interactions of monetary and macroprudential policies in maintaining financial stability; third, showing roles of fiscal policy as the ELB constraint binds.

*JEL classification*: C32, E37, E52, E58

*Keywords*: Monetary Policy; Integrated Policy Framework; Semi-structural Model; Financial Stability;

---

*The views expressed herein are those of the authors, and do not necessarily represent those of the Bank of Thailand. We thank Chutiorn Tontivanichanon for her assistance on the macro-financial part of our model. We are also grateful for comments from Phurichai Rungcharoenkitkul, Pongsak Luangaram, Pisut Kulthanavit, Titanun Mallikamas, Rungporn Roengpitya, Surach Tanboon and Wasin Rojayaroon.

[†]Corresponding author: SavaphoH@bot.or.th. Address: 273 Samsen Road, Wat Samphraya, Phra Nakhon, Bangkok 10200, Thailand.

# 1 Introduction

Regardless of their policy framework, central banks often count on multiple policy tools to fulfill their macroeconomic objectives. For inflation-targeting central banks, especially in emerging market economies (EMEs), foreign exchange (FX) intervention and capital flow measures are occasionally employed alongside the conventional interest rate policy to deal with exchange rate volatility.[1] Major central banks also responded to the global financial crisis in 2008-09 with a variety of unconventional measures. Meanwhile, they have increasingly relied upon macroprudential regulations to mitigate financial stability risks. The recent COVID-19 pandemic, which results in economic depression, accelerates such an integrated policy use. Thailand is not an exception, since the Bank of Thailand has employed a wide range of policy tools to pursue its macro-financial stability objectives over the past few decades.

The central bank usage of integrated policy has been well ahead of its theoretical foundations. This has recently motivated an analytical research to formulate a so-called "integrated policy framework (IPF)" to recommend how best to combine these policy tools. The IMF-led efforts pave the way with the recent contributions by Basu et al. (2020) and Adrian et al. (2020b), who have developed conceptual and quantitative IPF models, respectively. By incorporating real world imperfections and relevant sources of shocks, their models help rationalize the integration of tools in macroeconomic stabilization within the EMEs context.[2] These models should benefit the future development of policy analysis models at most central banks, whose model currently cannot accommodate analyses of alternative policy tools beyond the conventional interest rate policy. At the Bank of Thailand, the existing Monetary Policy Model (MPM) still features a single instrument, while not being elaborate enough to take more policies into consideration.

Against this backdrop, this paper aims to develop a medium-sized semi-structural

[1] See Chapter II of the BIS Annual Economic Report 2019 on "Monetary policy frameworks in EMEs: inflation targeting, the exchange rate and financial stability", which discusses EMEs' characteristics that motivate the use of multiple tools to respond to capital flow and associated exchange rate volatility. The paper highlights the 'financial channel' of exchange rates, which plays an important role in aggravating monetary policy trade-offs.

[2] See Borio and Disyatat (2021), who shed light on practical constraints associated with the temporal dimension of the various policies and tools, which make policy integration less feasible.

model of the Thai economy for an integrated policy analysis.[3] The development, first, entails the augmentation of financial and fiscal sectors to an otherwise standard open-economy macroeconomic model. The macro-financial structure in our model closely follows that of Ehrenbergerova and Malovana (2019), with credit, property prices and non-performing loans (NPLs) being key financial variables, allowing for the forceful feedback loops between real and financial sectors. Importantly, this extension allows us to identify the impact of various policy tools at the central bank's disposal, and hence greatly supports integrated policy analyses. The fiscal sector, meanwhile, simply includes a fiscal policy reaction function and public debt dynamics.

Second, the model features multiple sources of nonlinearity, bringing about asymmetric responses to shocks. These nonlinearities aim to reproduce macroeconomic tail events that pose challenges toward economic stabilization. The first one is the effective lower bound (ELB) on the policy rate, which constrains the central bank's ability to avert crises. Similarly, there is a constraint on fiscal policy, as the government's borrowing rate rises nonlinearly with the public debt level. Several nonlinearities occur within the financial sector; intended to capture the possibility of a credit crunch and widespread default in crisis times, and the consequence of low-for-long interest rates on future credit quality. We also allow for a nonlinear impact of exchange rate appreciations on economic activity. In addition, to capture costs of debt-driven growth, we assume that excessive private sector debt results in a too large debt burden that can negatively impact economic activity. These features render the economy more susceptible to large, adverse shocks, and so call for extra policy intervention to either prevent or mitigate them.

Third, we include multiple policy tools to satisfy macroeconomic objectives. In addition to the policy rate, our model has been made possible the ability to analyze FX intervention, macroprudential regulations such as credit control measures, and various financial measures employed during the COVID-19 pandemic. Moreover, fiscal policy is also present in this model. The interaction between fiscal and monetary policies has gained attention in the academic and policy debate, as the pandemic has reinforced the

[3] To our knowledge, the first attempt to develop Thailand's semi-structural model for a monetary policy analysis is by Pongsaparn (2008). We choose to work with a semi-structural model due to its tractability and flexibility when compared to full-fledged DSGE models.

prevailing low interest rate regime and called for a greater role of fiscal policy.[4] How both policies coordinate in supporting economic recovery going forward will be of great interest.

Last, given the high level of risks and uncertainties facing the economy, we attempt to quantify these risks by simulating the future distribution of output gaps and other variables of interest. Due to the embedded nonlinearities, the model is capable of producing skewed distributions of future economic activities. We, particularly, focus on the left tail of the output gap distribution, known as 'GDP-at-Risk', which informs policymakers about the likelihood of crisis events. Since our model features extensive real-financial sector linkages, such tail risks naturally inform us the development of tail macroeconomic risks associated with financial vulnerabilities. The 'GDP-at-Risk', therefore, serves us as a useful macro-financial risk indicator, making our model well-equipped to assess policies aimed at mitigating risks to financial stability.

Our model possesses the following properties. The impulse responses highlight non-trivial roles of macro-financial linkages and the associated feedback loops in shock propagation. In the face of negative output shocks, credit risks worsen while credit extension deteriorates, both exacerbating the decline in economic activity. Meanwhile, shocks originated from the financial sector are found to have a non-negligible impact on the real economy. Interestingly, our model captures intertemporal trade-offs between a short-term credit expansion and a longer-term worsened economic outcome. In addition, economic dynamics are proven vulnerable to large, adverse NPL shocks, thanks to the possibility of credit crunch that follows. We employ our model to perform economic forecasting in the aftermath of the COVID-19 pandemic. The results highlight the apparent, negative consequences of an ELB constraint. In particular, we show that without such constraint, the Taylor rule would recommend very-negative interest rate policy, which enabled much faster economic recovery. Moreover, the forecasted distribution of future economic activity shows a fat left tail, which underscores roles of the model's nonlinearity in generating macro-financial tail risks. This also signals lingering financial vulnerabilities to be addressed.

[4]See, for example, recent contributions from Hofmann et al. (2021). Borio (2019) also includes fiscal and structural policies in a more holistic macro-financial stability framework.

To shed light on potential gains from policy complementarity, we apply this model in three integrated policy analyses in Thailand's context. First, we assess several measures in tackling the current pandemic-induced economic crisis. We show that the Bank of Thailand's financial measures, including soft loans and regulatory forbearance, yield substantial benefits toward an economic recovery going forward. Without them, an economic downturn risks being exacerbated by the nonlinearity governing credit growth and NPL dynamics. Moreover, in the face of sharp baht appreciation over the next few years, more active FX intervention to slow down the pace of exchange rate changes can help lessen its adverse, nonlinear impact on economic activity. Second, we apply our model to assess policy integration to address longer-term financial stability risks that arise from high household debt. The simulation shows that implementing macroprudential policy, namely credit restrictions, helps improve intertemporal trade-offs the economy faces as the central bank attempts to curb rising debt. That is, compared to using monetary policy to lean against the wind, macroprudential policy is rather effective in reducing financial stability risks, as measured by the significantly lower probability of tail events over the long term, despite some short-term costs to output. Last, we analyze whether fiscal policy could step in to complement other tools to achieve a better economic outcome. We find that an aggressive fiscal policy during the COVID-19 recovery can benefit economic stabilization by stimulating demand and reducing the output gap at its widest point. The drawback, the future decreases in government spending to delever the high public debt, is an acceptable trade-off as they happen when the output gap is nearer to zero.

*Related Literature:* Although our model closely follows the macro-financial structure of Ehrenbergerova and Malovana (2019)'s model, we make contributions in several aspects. Importantly, we embed a comprehensive list of tools to complement the conventional interest rate policy in economic stabilization. We also include multiple sources of nonlinearity, including crucial ingredients in crisis times such as ELB. The resulting model, therefore, improves state-of-the-art semi-structural models widely used at central banks. Given its complex structure, it offers an analytical tool for conducting insightful policy analyses to achieve a more desirable economic outcome.

This study also relates to four other key strands of literature. First, it fits into a large group of articles analyzing financial frictions in structural macroeconomic models, which put an emphasis on asymmetric information among borrowers and lenders, and the financial accelerator. These include, for example, Bernanke et al. (1999), Kiyotaki and Moore (1997) and Gertler and Kiyotaki (2010), the latter focusing on frictions among intermediaries themselves. In the context of semi-structural settings, modelling of macro-financial linkages is rather scarce. In particular, the model based on Berg et al. (2006), which becomes the main policy analysis model for many central banks, does not take much consideration of such linkages. Although some variants of Berg et al.'s model include bank lending conditions (Benes et al., 2017), such variable may not capture diverse aspects of the financial system such as non-bank lending activities. Others follow Bernanke et al. (1999) by including credit risks and an interest rate spread, but still lacks comprehensive channels to analyze integrated policies.

Our paper also relates to literature studying the interaction between policy tools, notably the complementarity of monetary and macroprudential policies in stabilizing business and financial cycles. Previous studies include Agénor et al. (2012) and Unsal (2013), who examine a joint use of these policies in addressing financial instability originated from capital flows. In response to the 2008-09 crisis, the coordination between loan-to-value (LTV) limits and monetary policy have also been widely studied in the model with housing (see, for example, Rubio and Carrasco-Gallego (2014) and Wongwachara et al. (2018)). However, to our knowledge, only a few articles focus on credit restrictions aimed at curtailing household debt. Our paper is among the very first attempts.

In addition, a handful of macro models have attempted to include an ELB on the policy rate (see, for example, Eggertsson and Woodford (2003) and Lepetyuk et al. (2017)). As argued by Chung et al. (2012), standard macro models potentially understate the probability of policy rate hitting zero, rendering them ineffective in predicting equilibrium during crises, and tend to under-weight the necessity of other policies in mitigating any adverse effects from such a constraint. Our paper confirms the significance of ELB for economic dynamics during crisis times.

Last, our work also fits into recent literature that links the current macro-financial conditions to the distribution of future economic growth, which allows policymakers to quantify macro-financial risks in terms of growth and monitors the evolution of risks to economic activity over time (Prasad et al. (2019) and Adrian et al. (2019)). Adrian et al. (2020a) also attempt to include endogenous macro-financial risks into the standard New Keynesian model, by linking conditional volatility of output gaps to financial conditions. Our work, however, is closer to Aikman et al. (2021), who replicate the empirically observed fat left tail of the GDP distribution by modelling three key nonlinearities: ELB, a credit crunch and debt deleveraging. We extend by adding more sources of nonlinearity that are relevant in the context of Thailand.

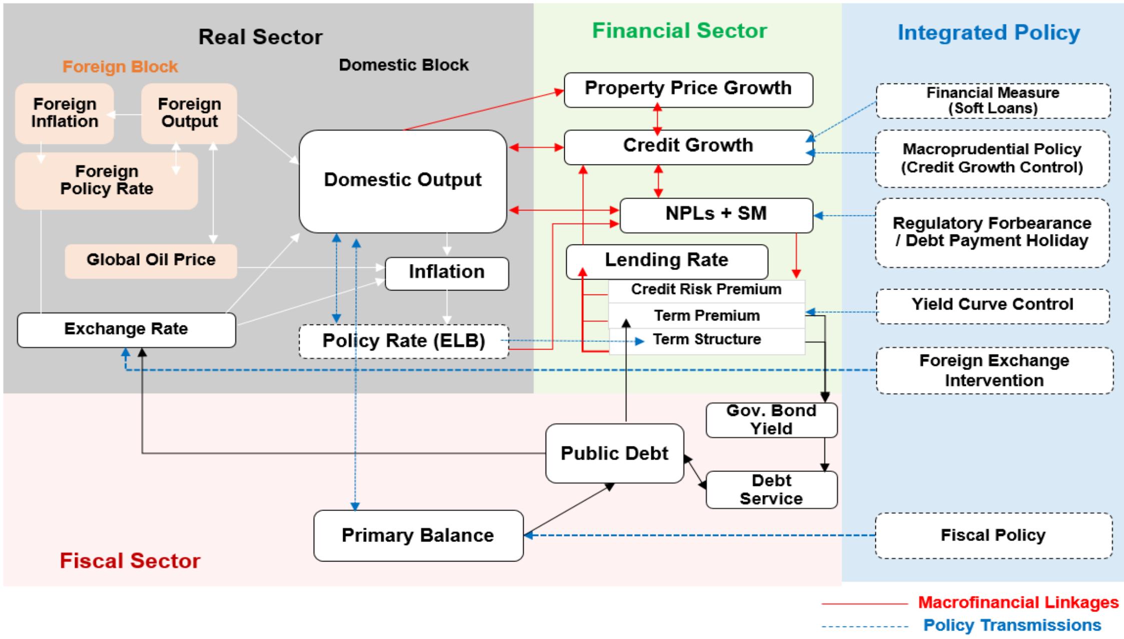
The organization of the paper is as follows. Section 2 describes the structure of the model by elaborating the list of underlying behavioral equations. Section 3 gives the details about the calibration and estimation of the model's parameters. In Section 4, we examine the resulting dynamic responses to shocks, and then show applications of our IPF model for integrated policy analyses in Section 5. The paper ends with concluding remarks in Section 6.

# 2 The Model

In this section, we describe behavioral equations that constitute the model. Our model consists of four main blocks, namely, the foreign block, the domestic block, the financial block, and the fiscal block. The domestic block comprises four key equations: IS equation, PC equation, monetary policy rule and UIP condition, all of which are standard equations for most open-economy New-Keynesian models. Meanwhile, our financial block contains credit, property prices and non-performing loans (NPLs) as three key financial variables that generate feedback loops back and forth to the real economy. Finally, the fiscal block consists of the fiscal policy rule and government debt dynamics, which interact with output and interest rates from the previous blocks. As stated earlier, to account for dynamics of the economy during a non-normal situation, our model also features various sources of nonlinearity, ranging from an effective lower bound (ELB) on the policy rate to a nonlinear relationship between several real and financial variables.

Figure 1 summarises the structure of the model, which captures several salient features of the Thai economy. First, being a small open economy, Thailand is prone to

Figure 1: Overview of Model Structure




external disturbances. This model permits various channels whereby shocks originated abroad affect domestic economic activity and inflation. Second, regarding exchange rates, the Thai baht has experienced an appreciation trend over the past two decades. One of the main causes is arguably a sustained, sizable current account surplus, making the baht a safe haven for foreign investors. We embed this feature into the UIP condition. The next feature revolves around the issue of domestic financial stability risk. Thai household debt has risen significantly in the past several years and may result in a too large debt burden that dampens the current recovery path out of the COVID-19 crisis. Our nonlinear 'debt burden' channel will capture this feature. The last one concerns the low level of Thai policy rate over recent periods, comparable to that in advanced economies, which raises the probability of reaching a lower bound. An ELB constraint should, thus, become a important model ingredient, if one wishes to attain accurate economic forecasts and reliable policy analyses during crises.

## 2.1 Real Economy

### 2.1.1 Foreign Block

The foreign block contains economic dynamics of Thailand's major trading partners, and is summarized by a standard closed-economy three-equation model plus dynamics for global oil prices. A foreign IS equation describes movements of a foreign output gap ($\hat{y}_t^*$), which measures foreign economic activity relative to its potential:

$$\hat{y}_t^* = \theta_{y,f}^* \hat{y}_{t+1}^* + \theta_{y,b}^* \hat{y}_{t-1}^* - \beta_r^* \hat{r}_t^* + \epsilon_t^{y^*}. \quad (1)$$

The current foreign output gap depends on both its past and expected future gaps, as well as a foreign real interest rate gap ($\hat{r}_t^*$). The latter is the difference between a foreign real interest rate and its neutral level. Positive real interest rate gaps exert tightening pressures on economic activity.[5] It is to note that, throughout this paper, we define gap variables as follows:

$$\hat{x}_t = x_t - \bar{x}_t,$$

i.e., deviations of a variable $x_t$ of its trend value ($\bar{x}_t$), the latter obtained by applying a Kalman filter. Except for real interest rates, current account ratios and public debt-to-GDP target, $x_t$ are in natural logarithms multiplied by 100. Hence, all gap variables are measured in percentage.

A foreign Philips curve equation ($\pi_t^*$) is close to the hybrid New-Keynesian Philips curve, where current inflation depends on inflation expectations as well as past inflation with some degree of indexation to central banks' inflation target:[6]

$$\pi_t^* = \theta_{\pi,f}^* \pi_{t+1}^* + \theta_{\pi,b}^* \pi_{t-1}^* + (1 - \theta_{\pi,f}^* - \theta_{\pi,b}^*)\pi^* + \alpha_y^* \hat{y}_t^* + \alpha_{\pi^{en}}^* (\pi_t^{en,*} - \pi^{en,*}) + \epsilon_t^{\pi^*}. \quad (2)$$

Foreign output gaps capture demand-pull inflationary pressures, whereas changes in global oil prices ($\pi_t^{en,*}$) represent the main supply-side driver of foreign inflation. Global oil prices are, in turn, driven by foreign output gaps, which indicate demand for oil

[5] A real interest rate equals a nominal interest rate ($i_t$) minus one-year-ahead expected inflation, i.e., $r_t^* = i_t^* - \pi_{yoy,t+4}^*$, where $\pi_{yoy,t}^*$ is a year-on-year change in foreign consumer price index. The neutral policy rate measures the rate at which monetary policy is neither contractionary nor expansionary.

[6] Inflation is an annualized quarter-on-quarter change in consumer price index: $\pi_t^* = 4(cpi_t^* - cpi_{t-1}^*)$.

consumption:

$$\pi_t^{en,*} = \rho^*_{\pi^{en}}\pi_{t-1}^{en,*} + (1-\rho^*_{\pi^{en}})\pi^{en,*} + \eta^*\hat{y}_t^* + \epsilon_t^{\pi^{en,*}}. \tag{3}$$

Foreign monetary policy ($i_t^*$) is described by the following Taylor rule, where the policy rate responds to the current output gap and a one-year-ahead forecast of an inflation deviation from target:

$$i_t^* = \rho_i^* i_{t-1}^* + (1-\rho_i^*)[\bar{r}_t^* + \pi^*_{yoy,t+4} + \phi_y^*\hat{y}_t^* + \phi_\pi^*(\pi^*_{yoy,t+4} - \pi^{target,*})] + \epsilon_t^{i^*}. \tag{4}$$

### 2.1.2 Domestic Block

As stated earlier, the structure of the Thai economy is represented by a standard open-economy New-Keynesian model. An open-economy IS equation postulates that domestic economic activity or output gap ($\hat{y}_t$) depends on a foreign output gap and a real exchange rate gap ($\hat{z}_t$), in addition to a real interest rate gap:[7]

$$\begin{aligned}\hat{y}_t = \theta_{y,f}\hat{y}_{t+1} + \theta_{y,b}\hat{y}_{t-1} - \beta_r\hat{r}_t - \beta_z\hat{z}_t - \Psi_y(\Delta s_t, \hat{y}_t) + \beta_{y^*}\hat{y}_t^* + \beta_{cred}(\Delta cred_t - \Delta cred)\\ - \beta_{npl}\hat{npl}_t + \beta_{pdeficit}(pdeficit_t - pdeficit_t^T) - \Psi_y(\widehat{creditgdp}_t) + \epsilon_t^y.\end{aligned} \tag{5}$$

The real exchange rate gap measures a deviation of a real exchange rate from its equilibrium level. Positive values of such gap correspond to domestic currency overvaluation, which adversely impacts the country's price competitiveness. Moreover, the IS equation has macro-financial linkages embedded, whereby credit growth ($\Delta cred_t$) and an NPL gap ($\hat{npl}_t$) affect domestic output. Whenever credit growth exceeds its steady-state level, it exerts a positive impact on the output gap, hence capturing credit-supply effects on economic activity. Meanwhile, positive values of the NPL gap imply higher firm bankruptcy, which results in falling employment and output. Fiscal policy can also affect the output gap via the primary deficit ($pdeficit_t$), whose definition and dynamics will become apparent in the fiscal block.

It is worth mentioning the presence of the nonlinear $\Psi$ functions. As salient features alluded to earlier, exchange rates and private sector debt can exert a strong,

[7] Again, a domestic real interest rate equals a nominal interest rate minus expected headline inflation over one year ahead: $r_t = i_t - \pi^{cpi}_{yoy,t+4}$.

adverse impact on output under certain circumstances. For exchange rates, the export-driven economy is particularly vulnerable to a sharp baht appreciation that occurs when the output gap is negative; $\Psi_y(\Delta s_t, \hat{y}_t) = \Psi_y(\Delta s_t) * I(\hat{y}_t < 0)$ measures such nonlinear impact. Meanwhile, there exists a 'debt burden' effect that starts to impact the economy once a private credit-to-GDP gap ($\hat{creditgdp}$) reaches a certain threshold.[8] Generally speaking, this channel helps capture risks emanated from excessive financial vulnerabilities that could drag down future real economic activity, as argued in Filardo and Rungcharoenkitkul (2016). The details of every nonlinear function are provided in Section 3.3.

Regarding prices, we describe separately dynamics of the three main components of headline inflation, namely, core inflation, energy inflation and raw food inflation. For core inflation ($\pi_t$), domestic economic activity exerts pressures on inflation through both level and change in the output gaps:

$$\pi_t = \theta_{\pi,f}\pi_t^e + \theta_{\pi,b}\pi_{t-1} + (1-\theta_{\pi,f}-\theta_{\pi,b})\pi + \alpha_y(\hat{y}_t - \kappa^*\hat{y}_t^*) + \alpha_{\Delta y}(\hat{y}_t - \hat{y}_{t-1})$$
$$+ \alpha_{\pi^m}(\pi_t^m + \Delta\bar{z} - \pi^{cpi}) - \alpha_z\hat{z}_t + \alpha_{\pi^{rf}}(\pi_t^{rf} - \pi^{rf}) + \alpha_{\pi^{en}}(\pi_t^{en} - \pi^{en}) + \epsilon_t^{\pi}. \quad (6)$$

External drivers of inflation include real exchange rate gaps as well as import price inflation ($\pi_t^m$). In addition, the equation allows for an indirect impact from changes in prices of raw food ($\pi_t^{rf}$) and energy ($\pi_t^{en}$), both of which are a production factor for several goods and services within the core inflation basket. It is also to note that inflation expectations ($\pi_t^e$) will not be purely model-consistent, but can also depend on the inflation target for the sake of model stability.

Other prices have simpler dynamics:

$$\pi_t^{im} = \pi_t^* - \Delta s_t, \quad (7)$$

$$\pi_t^{en} = \rho_{\pi^{en}}\pi_{t-1}^{en} + (1-\rho_{\pi^{en}})\pi^{en} + \gamma_{\pi^{en}}[(\pi_t^{en,*} - \pi^{en,*}) - (\Delta s_t - \Delta s))] + \epsilon_t^{en}, \quad (8)$$

$$\pi_t^{rf} = \pi^{rf} + \epsilon_t^{rf}, \quad (9)$$

$$\pi_t^{cpi} = \omega_{\pi^{rf}}\pi_t^{rf} + \omega_{\pi^{en}}\pi_t^{en} + (1-\omega_{\pi^{rf}}-\omega_{\pi^{en}})\pi_t, \quad (10)$$

[8] The ratio of private credit to GDP ($creditgdp_t$) equals $\frac{\sum_0^3 ncredit_{t-i}}{\sum_0^3 y_{t-i}^n}$, where nominal credit growth $\Delta ncredit_t = \frac{\Delta cred_t}{4} + \frac{\pi_t^{cpi}}{4}$ and nominal GDP growth $\Delta y_t^n = \frac{\Delta y_t}{4} + \frac{\pi_t^{cpi}}{4}$.

where import price inflation is basically a function of foreign inflation and a change in nominal exchange rates. Energy inflation depends on a change in global oil prices as well as a change in nominal exchange rates ($\Delta s_t$), reflecting the fact that domestic retail oil is mostly imported. Meanwhile, raw food inflation ($\pi^{rf}$) solely depends on stochastic shocks, since it is mainly subject to unexpected temporary events causing supply fluctuations, such as volatile weather conditions and diseases. Last, we can compute headline inflation ($\pi_t^{cpi}$) as the weighted sum of the three sub components.[9]

Similar to its foreign counterpart, the domestic policy rate responds to the current output gap and a one-year-ahead forecast of a core inflation deviation from target, while also displaying persistence:

$$i_t^{taylor} = \rho_i i_{t-1}^{taylor} + (1-\rho_i)[\bar{r}_t + \pi_{yoy,t+4}^{cpi} + \phi_y \hat{y}_t + \phi_\pi(\pi_{yoy,t+4} - \pi^{target})] + \epsilon_t^i. \tag{11}$$

Despite the fact that headline inflation has been made the inflation target since 2015, core inflation, which better reflects underlying inflationary pressures, is a more relevant inflation measure towards monetary policy decision-makings. Headline inflation, mainly driven by temporary energy and raw food price shocks, is often too volatile.

One of the model's important features is that the policy rate cannot be lower than a certain threshold, so-called an ELB. We impose an occasionally binding constraint, where the policy rate is constrained at the ELB whenever the level prescribed by the monetary policy rule above falls below such a lower bound. A simulation exercise in the following section will show that this constraint derails the ability of monetary policy to support the economy in the face of large, adverse shocks. While an ELB is normally assumed at zero percent, known as a zero lower bound (ZLB), it can also take negative or positive values.[10] So, we have:

$$i_t = max(i_t^{taylor}, ELB). \tag{12}$$

Nevertheless, it is to note that our model is at risk of instability when the policy rate hits

[9] We calibrate the weights of energy and raw food inflation at 10% and 15%, respectively, which roughly correspond to the consumption share used in the construction of headline inflation by the Ministry of Commerce.

[10] On one hand, a few advanced central banks have already implemented negative interest rate policy. On the other hand, some central banks may refuse to cut rates to zero due to perverse effects of doing so or concerns over financial instability, rendering a positive ELB.

the ELB. To ensure model stability, we allow the formation of inflation expectations to assign more weight to the central bank's inflation target during the constrained periods:

$$\pi_t^e = (1 - \omega_t^{fg})\pi_{t+1} + \omega_t^{fg}\pi^{target}. \tag{13}$$

This nominal anchor helps prevent the economy from undergoing a deflationary spiral. Without such anchoring, inflation would decline sharply, thereby pushing up real interest rates and exacerbating an economic downturn.[11]

Next, we describe dynamics of nominal exchange rates:

$$\begin{aligned} s_t =& \rho_s(s_{t-1} + \frac{\Delta\bar{z} + \pi^* - \pi^{cpi}}{4}) + (1 - \rho_s)[s_{t+1} + \frac{(i_t - i_t^* - prem_t)}{4} + \gamma_{ca}\hat{ca}_t] \\ & - \gamma_{fxi} fxi_t + \gamma_{pflows} pflows_t + \epsilon_t^s, \end{aligned} \tag{14}$$

where an increase in $s_t$ implies the strengthening of the domestic currency value. Following the IMF's Quarterly Projection Model (QPM) first introduced by Berg et al. (2006), the UIP condition allows for persistence in exchange rates, apart from the usual no-arbitrage condition related to an interest rate differential and risk premium. A negative coefficient on premium ($prem_t$) assumes that the domestic interest rate is higher than its foreign counterpart to compensate for country specific risks. Otherwise, the domestic currency will depreciate. Another important modification to match empirical evidence is to allow a current account surplus ($\hat{ca}_t$) to exert appreciation pressures on the exchange rates. Furthermore, FX intervention ($fxi_t$), namely, purchases or sales of foreign currencies in the FX markets to influence exchange rates, is also present in the equation. The parameter $\gamma_{fxi}$ measures its effectiveness.[12] Last, to account for short-term exchange rate volatilities, we include net foreign portfolio flows ($pflows_t$) into debt and equity markets.

[11] In normal time, the anchoring mechanism is not necessary for model stability. We assume the following error function:

$$\omega_t^{fg} = \eta[(-erf(2(i_t^{taylor} - ELB) + 1.5) + 1)/2].$$

This function also implies that weight given to the inflation target is sufficiently high to ensure stability, but low enough so that model dynamics are not much distorted.

[12] While the FX intervention helps mitigate excessive exchange rate volatilities, it is not without costs. In the Appendix, we show its costs in terms of 'accounting' losses incurred on the central bank's balance sheet. Moreover, there exists a political-economy constraint, e.g. from the threat of being labelled a currency manipulator.

Dynamics for each exchange-rate determinant are as follows:

$$prem_t = \rho_{prem} prem_{t-1} + (1-\rho_{prem}) prem + \gamma_{debt}(\frac{\sum_{i=0}^{3} debt_{t+i}}{4} - debt^T) + \epsilon_t^{prem}, \quad (15)$$

$$\hat{ca}_t = \rho_{ca}\hat{ca}_{t-1} - \theta_z^{ca}\hat{z}_t - \theta_y^{ca}\hat{y}_t + \theta_{y^*}^{ca}\hat{y}_t^* + \epsilon_t^{ca}, \quad (16)$$

$$fxi_t = \omega_s(\Delta s_t - \Delta s) + \omega_z \hat{z}_t + \epsilon_t^{fxi}, \quad (17)$$

$$pflows_t = \rho_{pflows} pflows_{t-1} + \omega_p(i_t - i_t^* - prem_t + \Delta s_{t+1}) + \epsilon_t^{pflows}. \quad (18)$$

The risk premium responds to the current and expected deviations of public debt-to-GDP ratio from the government's target. Like in Baksa et al. (2020), the country's risk perception is higher if the public debt-to-GDP ratio increases. A current account gap depends on both domestic and foreign output gaps as well as a deviation of a real exchange rate from fundamentals. Given Thailand's continued current account surpluses, we allow for a non-zero current account trend value in the long run. Following Montoro and Ortiz (2020), we assume that FX intervention responds to both the change in nominal exchange rates and the real exchange rate gap. Such an intervention rule signals the central bank's intention to reduce short-run excessive exchange rate volatility and longer-run exchange rate misalignment. Last, as in Ghosh et al. (2015), portfolio flows respond to arbitrage opportunities in the international bond markets. A real exchange rate identity takes the following form:

$$\Delta z_t = \Delta s_t - \pi_t^* + \pi_t^{cpi}. \quad (19)$$

## 2.2 Financial Block (Macro-financial Linkages)

As opposed to fully-fledged DSGE models, the presence of macro-financial linkages in the context of semi-structural models is relatively scarce. In our model, the macro-financial structure will follow that of Ehrenbergerova and Malovana (2019), whose setting features (1) a financial accelerator through credit and credit risks, (2) a spiral between credit and property prices, and (3) a countercyclical credit risk premium that impacts credit extension and interest rates charged on loans. Simply put, credit growth, property prices and credit risks, the latter proxied by non-performing loans (NPLs), represent the 3 main macro-financial variables, which in turn depend on the state of the economy as well as monetary policy.

We extend the original setting of Ehrenbergerova and Malovana (2019) along two dimensions: different maturity for lending rates and nonlinearities. We consider two separate lending rates, which are of different maturity, i.e., 2 and 5 years. Our aim is to capture diverse types of credit, ranging from short-term working capital and personal loans to longer-term mortgages and term loans extended to corporates. Having multiple loan maturity in our model also enables us to explore the effects of implementing yield curve control (see Hirakata et al. (2019)), which aims at flattening the longer end of the yield curve, rather than influencing short-term rates.

We introduce four nonlinear relationships in this block, the first one being the nonlinear effect of NPLs on credit growth. More specifically, an increase in NPLs above a certain threshold exerts a large nonlinear effect on credit extension. This 'credit crunch' channel may be due to the binding capital regulation constraint, increases in loans loss provisioning that reduce supply of loanable funds, or a disproportionate rise in risk aversion. This feature is crucial in times of crises, which often precipitate a deterioration of credit quality and a more cautious credit extension.[13] The second and third sources of nonlinearity involve the NPL dynamics. Using ideas from Mohaddes et al. (2017) on the non-monotonic relationship between economic growth and NPLs, an output gap below a certain threshold can increase NPLs significantly, bringing about 'widespread default'. Moreover, thanks to literature on the 'risk-taking' channel of monetary policy, there is abundant empirical evidence of banks' increased risk appetite and lower lending standards during low-for-long periods.[14] In our model, we postulate that loans extended when the policy rates are sufficiently low could be riskier and lead to higher NPLs ex-post. This channel extends the benefit of leaning against the wind. The last nonlinearity in this block relates to the effect of higher public debt on term premium. This is to reflect the increase in perception of the government's default risk that rises along with a higher public debt burden.

We next describe our financial block in detail. The first macro-financial variable, credit growth, is driven by the output gap, the real lending rate gaps and growth

[13]See the macro stress test model of Borio et al. (2014) and Drehmann (2006), which emphasize this nonlinearity feature.

[14]Using Thai data, Ratanavararak et al. (2018) find that banks have an increased appetite for riskier loans when interest rates are low.

in property prices ($\Delta hp_t$):

$$\Delta cred_t = \rho_{cred}\Delta cred_{t-1} + (1-\rho_{cred})[\Delta cred + \theta_y^{cred}\hat{y}_t - \theta_{rlend,2y}^{cred}\hat{rlend}_t^{2y} - \theta_{rlend,5y}^{cred}\hat{rlend}_t^{5y} + \theta_{hp}^{cred}(\Delta hp_t - \Delta hp)] - \Psi_{cred}(\hat{npl}_t) + \epsilon_t^{cred}, \quad (20)$$

where the output gap captures demand for credit to facilitate household consumption and business investment. Property prices also matter thanks to their impact on collateral constraints a la Iacoviello (2005). Regarding real lending rate gaps, as stated above, we include both short-term and long-term lending rates ($\hat{rlend}_t^{2y}$ and $\hat{rlend}_t^{5y}$). Moreover, the nonlinearity in credit growth, triggered by the rise in NPLs above a certain threshold, is present in the equation via the term $\Psi_{cred}(\hat{npl}_t)$.

Second, property price growth depends on credit growth, the output gap and the real interest rate gap. Two-way interactions between credit and property price growth create a spiral that reinforces the model dynamics. Output and real interest rate gaps, meanwhile, reflect demand for housing consumption and discount rates, respectively:

$$\Delta hp_t = \rho_{hp}\Delta hp_{t-1} + (1-\rho_{hp})[\Delta hp + \theta_y^{hp}\hat{y}_t - \theta_r^{hp}\hat{r}_t + \theta_{cred}^{hp}(\Delta cred_t - \Delta cred)] + \epsilon_t^{hp}. \quad (21)$$

Third, NPL gaps, which measure credit risks in our model, will be a function of the output gap in the previous period, a real lending rate gap, and the past credit growth:[15]

$$\hat{npl}_t = \rho_{npl}\hat{npl}_{t-1} - \theta_y^{npl}\Psi_{npl}(\hat{y}_t)\hat{y}_{t-1} + \theta_{rlend,2y}^{npl}\hat{rlend}_t^{2y} + \theta_{cred}^{npl}(\Delta cred_{t-4} - \Delta cred) + \Psi_{npl}(i_{t-1}^{'}, \Delta cred_{t-1}^{'}) + \epsilon_t^{npl}. \quad (22)$$

The lagged impact from both economic and credit activities is in line with the findings of Nualsri et al. (2014). An intertemporal trade-off between current and future financial conditions occur in our model, whereby an increase in credit growth today will prompt a rise in NPL gaps in the future. The NPL equation also includes two nonlinear terms. The first is $\Psi_{npl}(\hat{y}_t)$, a regime-dependent parameter driving the output gap's incremental negative impact on NPLs when the economy is suffering from a crisis. Meanwhile,

[15]It is important to note that, since actual data suggest that NPLs do not display much variation and respond sluggishly to economic fluctuations, we include special-mention loans into the definition of NPLs. Under IFRS9, NPLs in our model includes loans in both Stage 2 and Stage 3.

$\Psi_{npl}(i'_{t-1}, \Delta cred'_{t-1}) = \Psi_{npl}(i'_{t-1}) I(\Delta cred'_{t-1} > 0)$, where $i'_{t-1} = \Sigma_{k=0}^{19} i_{t-1-k}$, captures the 'risk-taking' channel or the consequence of low-for-long interest rates on future credit quality. The indicator function $I(\Delta cred'_{t-1} > 0)$ ensures that this channel works only when credit expands.

Last, to show the pricing of credit risks, we describe how nominal lending rates are determined. Nominal lending rates ($ilend_t$) can be segregated into three components: term structure, term premium and credit risk premium. The term structure ($TS_t$) is an average of expected future policy rates over the corresponding horizon, say 8 or 20 quarters. We assume that a term premium for short-term bonds ($TP_t^{2Y}$) follows an autoregressive process, as the central bank stabilizes short-term market interest rates in accordance with the monetary policy stance. However, that for longer-term bonds ($TP_t^{5Y}$), like exchange rate risk premium in the UIP equation, responds to the country's anticipated public debt deviations from target. Such deviations, if excessive, will disproportionately raise risk premium, thereby tightening financial conditions for both private and public sectors. The nonlinear function $\Psi_{TP}(\frac{\sum_{i=0}^{3} debt_{t+i}}{4})$ captures this property. A credit risk premium ($CP_t$), meanwhile, depends on default risks. Below are equations for nominal lending rates, where $i \in \{2\text{y}, 5\text{y}\}$ and $j$ denotes the corresponding loan maturity in quarters:

$$ilend_t^i = \rho_{ilend,i} ilend_{t-1}^i + (1 - \rho_{ilend,i})(TS_t^i + TP_t^i + CP_t), \tag{23}$$

$$TS_t^i = \frac{1}{j} \sum_{k=1}^{j} i_{t+k}, \tag{24}$$

$$TP_t^{2y} = \rho_{tp,2y} TP_{t-1}^{2y} + (1 - \rho_{tp,2y}) TP^{2y} + \epsilon_t^{TP,2y}, \tag{25}$$

$$TP_t^{5y} = \rho_{tp,5y} TP_{t-1}^{5y} + (1-\rho_{tp,5y}) TP^{5y} + \theta_{debt}(\frac{1}{4}\sum_{i=0}^{3} debt_{t+i} - debt_t^T) + \Psi_{TP}(\frac{1}{4}\sum_{i=0}^{3} debt_{t+i}) + \epsilon_t^{TP,5y}, \tag{26}$$

$$CP_t = \rho_{cp} CP_{t-1} + (1 - \rho_{cp})(CP + \theta_{npl}^{cp} \hat{npl}_t) + \epsilon_t^{CP}. \tag{27}$$

The natural rate of interest for both lending maturity are as follows:[16]

$$\bar{rlend}_t^i = \rho_{\bar{rlend},i} \bar{rlend}_{t-1}^i + (1 - \rho_{\bar{rlend},i})(\bar{r}_t + TP^i + CP) + \epsilon_t^{rlend,i}. \tag{28}$$

[16] $rlend_t^i = ilend_t^i - \pi_t^{e,i}$, where $\pi_t^{e,i} = \frac{1}{j}\sum_{k=1}^{j} \pi_{t+k}$

## 2.3 Fiscal Block

The fiscal block consists of two main parts: the fiscal policy rule and government debt dynamics. Following Hofmann et al. (2021), the fiscal policy rule, expressed in terms of the ratio of primary deficit to GDP ($pdeficit_t$), reflects the government's intention to stabilize economic activity and level of public debt. Specifically, the primary balance responds to the economy's output gap and the expected deviation of a public debt-to-GDP ratio from the government's target:

$$pdeficit_t = \rho_{pdeficit} pdeficit_{t-1} + (1 - \rho_{pdeficit}) pdeficit^T_{t-1} - \phi^g_y \hat{y}_t - \phi^g_{debt}(\frac{1}{4}\sum_{i=0}^{3} debt_{t+i} - debt^T_t) + \epsilon^{pdeficit}_t. \quad (29)$$

On one hand, the government acts as a countercylical buffer for the economy. On the other hand, the government is also aware of their debt burden; whenever debt exceeds the desired level, the government will tend to cut the deficit, or even engineer a budget surplus, to deleverage and improve their fiscal position. The inertial term suggests that the government also attempts to smooth their spending. We assume the debt target ($debt^T_t$) is time-varying to reflect the government's preference at a given period of time.[17] Over the long term, the primary balance also adjusts toward $pdeficit^T_t$, the level that is consistent with debt target.

The overall fiscal budget deficit ($deficit_t$), meanwhile, is the sum of primary deficit and interest payment on existing debt ($debtservice_t$), which depends on the yield of government bonds ($effyield_t$):

$$deficit_t = pdeficit_t + debtservice_t, \quad (30)$$

$$debtservice_t = effyield_{t-1}(1 - \frac{1}{1 + \Delta y^n_t}) debt_{t-1} + \epsilon^{debtservice}_t, \quad (31)$$

$$effyield_t = \frac{1}{12}\sum_{i=0}^{11} yield^{5y}_{t-i}. \quad (32)$$

Typically, the government issues bonds of different maturity to fund their operations, and the total debt burden is dependent on the yields when those securities are issued. Since

[17] The time-varying nature of debt target ensures that large fiscal stimulus does not necessarily result in large austerity in the subsequent periods, since debt target may adjust upward.

the majority of government-issued securities are long-maturity bonds, we simplify and choose the effective rate to be based on the average of the 5-year government bond yields over the past three years. The debt service burden, thus, provides a link to monetary policy.[18]

Next, we describe the dynamics of the public debt-to-GDP ratio, which are a key constraint to fiscal policy. This feature is roughly in line with the model developed by Baksa et al. (2020). The ratio is determined by the previous period's level, adjusted by nominal GDP growth, and the current period's overall budget deficit:

$$debt_t = (1 - \frac{1}{1 + \Delta y_t^n})debt_{t-1} + deficit_t + \epsilon_t^{debt}. \tag{33}$$

As is standard in the literature, economic growth, inflation and the central bank's policy rate are all important determinants of public debt evolution. Given the path of the government's desired debt target, $debt_t^T$, we can compute the primary deficit level consistent with such target based on Equations (34) and (35) below:

$$pdeficit_t^T = deficit_t^T - \frac{1}{4}\sum_{i=0}^{3} debtservice_{t-i}, \tag{34}$$

$$deficit_t^T = debt_t^T[1 - \frac{1}{1 + \Delta \bar{y} + \pi^{cpi}}]. \tag{35}$$

From Equation (34), facing with the large debt service burden, the government cannot afford too large a primary deficit in order to meet overall budget deficit target ($deficit_t^T$).

# 3 Model Parameters

We obtain most of the model's parameter values through Bayesian estimation. Model equations are firstly linearized around the steady state. The estimation of the posterior distribution of the parameters is done using the Metropolis algorithm. At the same time,

[18]We obtain 5-year government bond yields from adding up the 5-year TS and TP components, described earlier: $yield_t^{5y} = TS_t^{5y} + TP_t^{5y}$.

we obtain the following evolution of trend variables through the Kalman filter:

$$\bar{x}_t = \rho_{\bar{x}}\bar{x}_{t-1} + (1-\rho_{\bar{x}})\bar{x} + \epsilon_t^{\bar{x}}, \bar{x}_t \in \{\bar{r}_t, \bar{r}_t^*, \bar{ca}_t, \bar{debt}_t^T\},$$

$$\Delta\bar{x}_t = \rho_{\Delta\bar{x}}\Delta\bar{x}_{t-1} + (1-\rho_{\Delta\bar{x}})\Delta\bar{x} + \epsilon_t^{\Delta\bar{x}}, \bar{x}_t \in \{\bar{y}_t, \bar{y}_t^*, \bar{z}_t, \bar{npl}_t\}.$$

Regarding data used in the estimation, we use a total of twenty two quarterly macroeconomic time-series as observables, including four foreign variables, eleven domestic variables, and seven macro-financial variables. Data employed in the estimation runs from 2005Q1 to 2019Q4. Please refer to Appendix C for a detailed description and data sources.

### 3.1 Steady State

There are two sets of steady states: one based on the historical average, the other on our own calibration taking into account structural shifts within the Thai and global economies over recent periods. Table 1 gives their details. For estimation purposes, we base the steady-state values upon the pre-COVID historical averages.[19] On average, potential output for Thailand and trading partners grow at 3.5 and 4 percent, respectively. The steady-state value of Thailand's core inflation is set at 1.75 percent, in line with the midpoint of the range target for core inflation during 2000-2014.[20] Steady-state headline inflation, meanwhile, equals 2.5 percent, implying significantly higher inflation dynamics for energy and raw food components. We assume the steady-state value for foreign inflation at 2 percent, in line with the inflation target of several advanced economies. The historical average of the Thai policy rate is approximately 3 percent, resulting in the steady-state neutral real interest rate of 1 percent. Such value is comparable to that of advanced economies. A real exchange rate, meanwhile, shows an appreciation trend growth of 1.5 percent per year. Supporting such trend is the non-zero steady state of Thailand's current account balance, which is as high as 3.5 percent of nominal GDP.

[19] We use the post-COVID steady state in our forecasting and policy analysis exercises in the following sections.

[20] The Bank of Thailand's inflation target since Inflation Targeting Framework adoption: core inflation within the range of 0-3.5% during 2000-2008; core inflation within the range of 0.5-3.0% during 2009-2014; headline inflation at 2.5+/-1.5% during 2015-2019; headline inflation within the range of 1.0-3.0% since 2020

Table 1: Steady State

| Variable | Description | Steady State Value | |
|---|---|---|---|
| | | Pre-COVID | Post-COVID |
| $\Delta\bar{y}^*$ | Foreign Potential Growth | 4% | 3% |
| $\pi^*$ | Foreign inflation | 2% | 2% |
| $\bar{r^*}$ | Foreign neutral real interest rate | 1% | 0% |
| $\Delta\bar{y}$ | Potential Growth | 3.5% | 3% |
| $\pi^{cpi}$ | Headline Inflation | 2.5% | 2% |
| $\pi$ | Core inflation | 1.75% | 1.5% |
| $\pi^{en}$ | Energy inflation | 4.75% | 3.5% |
| $\pi^{rf}$ | Raw food inflation | 4.75% | 3.5% |
| $\bar{r}$ | Neutral real interest rate | 1% | 0.33% |
| $\Delta\bar{z}$ | Changes in equilibrium real exchange rate | 1.5% | 0% |
| $\bar{ca}$ | Current account to GDP | 3.5% | 3.5% |
| $\Delta cred$ | Credit growth | 5% | 4% |
| $\Delta hp$ | Property price growth | 3.7% | 2% |
| $\Delta \bar{npl}$ | Growth of Trend NPLs | 3.5% | 4% |
| $ilend^{2y}$ | 2-year Nominal lending rate | 5.83% | 4.72% |
| $TP^{2y}$ | Term premium for 2-year loans | 0.38% | 0.1% |
| $TP^{5y}$ | Term premium for 5-year loans | 0.95% | 0.6% |
| $CP$ | Credit risk premium | 2.7% | 2.82% |
| $pdeficit$ | Primary deficit to GDP | 0.23% | 0.26% |
| $deficit$ | Deficit to GDP | 0.61% | 0.62% |
| $debt$ | Public debt to GDP | 41% | 50% |

Note: Steady states for pre-COVID periods are based on the historical average of actual data, while those for post-COVID periods are from expert judgment.

Regarding macro-financial variables, private credit to non-financial borrowers and property price index, on average, grow at an annualized rate of 5 and 3.7 percent, respectively. We assume steady-state growth of NPLs at 3.5 percent. The average nominal lending rate, meanwhile, is at around 5.83 percent. By observing the average spread between 2-year (5-year) government bond yields and the policy rates, we assume a steady-state term premium for 2-year (5-year) loans at 0.38 (0.95) percent. Last, based on Equation (23), we obtain an implied steady-state credit risk premium at 2.7 percent. For fiscal policy-related variables, the average ratio of public debt to GDP is at 41 percent. Given the trend GDP growth and 5-year bond yields specified above, they imply the steady-state ratios of primary deficit and overall budget deficit to GDP at 0.23 and 0.61 percent, respectively. As argued in Blanchard (2019), persistent budget deficit without exploding debt is plausible given lower real interest rates relative to economic growth.

## 3.2 Bayesian Estimation

We note that we do not rely solely on the Bayesian estimates. Some parameters are further calibrated to obtain more realistic dynamics of the model. Table 2 shows the resulting parameter values to be used in later analyses. The detailed prior and posterior distribution of all estimated parameters are shown in Appendix D. For parameters that exist in the Monetary Policy Model currently employed at the Bank of Thailand, the mean values of the prior distribution will mostly be based upon their calibrated value in that model. However, we also use expert judgement to reach the final prior distribution. Regarding parameters in the financial block, we primarily base their prior distribution on the estimates from Ehrenbergerova and Malovana (2019), but slightly adjust to match characteristics of the Thai economy. Meanwhile, the prior mean for standard deviations of shock processes will be based on their actual volatility. The type of prior distribution for each parameter closely follows the literature.

The estimated parameters, in most cases, are close to their priors. We impose expert judgement on a few parameters. First, we raise the value of the persistence parameter of both output gaps and core inflation. While too low output persistence renders economic growth too volatile, greater persistence in inflation matches well with the behaviour of inflation in recent periods. Second, on inflation dynamics, we reduce the parameter value governing the effects of import price inflation on core inflation, given the low import content within the core consumption basket. The response of core inflation to changes in output gaps is also adjusted downward to reflect the flattening of Phillips curve. Third, to prevent too strong deviations from a traditional UIP condition, we reduce both the exchange rate persistence and the response of exchange rates to current account adjustments. Fourth, the reaction of FX intervention to a real exchange rate gap is calibrated close to zero, to reflect the central bank's intention to reduce short-term exchange rate volatility rather than to govern the exchange rate path. Fifth, we increase the value of the parameter $\theta_{hp}^{cred}$, assuming a stronger house price-credit spiral.

Table 2: Parameter Calibration and Estimation

| Parameter | C/E | Value |
|---|---|---|
| *IS equation* | | |
| $\theta_{y,b}$ | C | 0.45 |
| $\theta_{y,f}$ | C | 0.30 |
| $\beta_r$ | E | 0.01 |
| $\beta_z$ | E | 0.05 |
| $\beta_{y^*}$ | E | 0.19 |
| $\beta_{cred}$ | E | 0.19 |
| $\beta_{npl}$ | C | 0.10 |
| $\beta_{pdeficit}$ | E | 0.91 |
| *PC equation* | | |
| $\theta_{\pi,b}$ | C | 0.70 |
| $\theta_{\pi,f}$ | E | 0.30 |
| $\alpha_y$ | E | 0.06 |
| $\alpha_{\Delta y}$ | E | 0.16 |
| $\alpha_{\pi^m}$ | C | 0.01 |
| $\alpha_z$ | E | 0.02 |
| $\alpha_{\pi^{rf}}$ | E | 0.01 |
| $\alpha_{\pi^{en}}$ | E | 0.01 |
| *Energy inflation equation* | | |
| $\rho_{\pi^{en}}$ | C | 0.30 |
| $\gamma_{\pi^{en}}$ | C | 0.10 |
| *Taylor rule* | | |
| $\rho_i$ | E | 0.88 |
| $\phi_y$ | E | 1.05 |
| $\phi_\pi$ | E | 1.57 |
| *UIP condition* | | |
| $\rho_s$ | C | 0.30 |
| $\gamma_{ca}$ | C | 0.04 |
| $\gamma_{FXI}$ | E | 0.14 |
| $\gamma_{portflows}$ | E | 0.13 |
| *Current account equation* | | |
| $\rho_{ca}$ | C | 0.75 |
| $\theta_z^{ca}$ | C | 0.08 |
| $\theta_y^{ca}$ | C | 0.10 |
| $\theta_{y^*}^{ca}$ | E | 0.75 |

| Parameter | C/E | Value |
|---|---|---|
| *Risk premium condition* | | |
| $\rho_{premium}$ | C | 0.75 |
| $\gamma_{debt}$ | E | 0.01 |
| *FX intervention rule* | | |
| $\omega_s$ | E | 0.21 |
| $\omega_z$ | C | 0.01 |
| *Portfolio flow equation* | | |
| $\rho_{portflows}$ | E | 0.25 |
| $\omega_p$ | E | 0.16 |
| *Credit growth equation* | | |
| $\rho_{cred}$ | E | 0.57 |
| $\theta_{rlend,2y}^{cred}$ | E | 0.23 |
| $\theta_{rlend,5y}^{cred}$ | E | 0.20 |
| $\theta_y^{cred}$ | E | 0.31 |
| $\theta_{hp}^{cred}$ | C | 0.50 |
| *Property price equation* | | |
| $\rho_{hp}$ | E | 0.41 |
| $\theta_{cred}^{hp}$ | E | 0.47 |
| $\theta_r^{hp}$ | E | 0.40 |
| $\theta_y^{hp}$ | E | 0.42 |
| *NPL equation* | | |
| $\rho_{npl}$ | E | 0.73 |
| $\theta_y^{npl}$ | E | 0.44 |
| $\theta_{cred}^{npl}$ | E | 0.22 |
| $\theta_{rlend}^{npl}$ | E | 0.16 |
| *Lending rate equation* | | |
| $\rho_{ilend,2y}$ | E | 0.75 |
| $\rho_{ilend,5y}$ | E | 0.89 |
| $\rho_{tp,2y}$ | E | 0.56 |
| $\rho_{tp,5y}$ | E | 0.15 |
| $\rho_{cp}$ | E | 0.65 |
| $\theta_{npl}^{cp}$ | E | 0.13 |
| $\rho_{r\bar{lend},2y}$ | E | 0.82 |
| $\rho_{r\bar{lend},5y}$ | E | 0.84 |
| $\theta_{debt}$ | E | 0.01 |

| Parameter | C/E | Value |
|---|---|---|
| *Primary deficit equation* | | |
| $\rho_{deficit}$ | E | 0.28 |
| $\phi_y^g$ | E | 0.019 |
| $\phi_{debt}^g$ | E | 0.01 |
| *Foreign IS equation* | | |
| $\theta_{y,b}^*$ | E | 0.18 |
| $\theta_{y,f}^*$ | E | 0.68 |
| $\beta_r^*$ | E | 0.16 |
| *Foreign PC equation* | | |
| $\theta_{\pi,b}^*$ | E | 0.68 |
| $\theta_{\pi,f}^*$ | E | 0.18 |
| $\alpha_y^*$ | E | 0.16 |
| $\alpha_{\pi^{en}}^*$ | E | 0.02 |
| *Foreign Taylor rule* | | |
| $\rho_i^*$ | E | 0.82 |
| $\phi_y^*$ | E | 0.40 |
| $\phi_\pi^*$ | E | 0.99 |
| *Global oil price equation* | | |
| $\rho_{\pi^{en,*}}$ | E | 0.27 |
| $\eta^*$ | E | 0.52 |
| *Trend Persistence* | | |
| $\rho_{\Delta\bar{y}}$ | E | 0.89 |
| $\rho_{\Delta\bar{y}^*}$ | E | 0.78 |
| $\rho_{\bar{r}}$ | E | 0.54 |
| $\rho_{\bar{r}^*}$ | E | 0.75 |
| $\rho_{\Delta\bar{z}}$ | E | 0.61 |
| $\rho_{\bar{ca}}$ | E | 0.74 |
| $\rho_{\Delta\bar{npl}}$ | E | 0.90 |
| $\rho_{debt^T}$ | E | 0.26 |

Note: E = Estimation, C = Calibration

### 3.3 Nonlinear function

In this subsection, we describe the functional form of all the nonlinear functions and explain the rationale we used to come up with the nonlinearity thresholds for each channel. The nonlinear functions are important model elements that help generate macroeconomic tail or crisis risks. We use the following function for all nonlinearities, where Table 3 provides the calibrated parameter values:

$$\Psi_y^1(x) = \phi_1[(erf(\phi_2 x + \phi_3) + \phi_4)][(\phi_2 x + \phi_3) + \phi_5(\phi_2 x + \phi_3)^2]. \quad (36)$$

This function ensures that a nonlinearity mechanism is triggered once the value of the corresponding variable exceeds the threshold $\bar{x}$. The marginal impact also rises as the value moves further away from such threshold.[21]

We next discuss the threshold for each nonlinear channel in turn. The graphical illustration of all nonlinear functions is provided in the Appendix E. For a *debt burden channel* in the IS equation, we follow Cecchetti et al. (2011) who estimate such threshold for 18 OECD countries during 1980-2010. While they found the estimate for the household and corporate debt to GDP at 85 and 90 percent, respectively, we set our $\bar{\hat{creditgdp}} = 160$ percent. The other nonlinearity impacting the IS curve, the *large E/R appreciation channel*, assumes that exporters begin to suffer from exchange rate appreciation whenever such change is sufficiently large and when economic activity is already below potential, exhausting their profit margins to a great extent. We calibrate the threshold $\Delta\bar{s}$ at 6 percent.

Turning to those nonlinearities taking place within the financial block, the *credit crunch channel* postulates that banks' credit supply becomes highly sensitive to loans default once NPL gaps rise above a certain value. Based on the fact that the Thai banking sector has been resilient and holds abundant capital above the requirement, we set a relatively high threshold for $\bar{\hat{npl}}$ (10 percent). We turn to two nonlinearities governing NPL dynamics. For the *widespread default channel*, triggered by deep economic recessions, we calibrate $\bar{\hat{y}} = -7$ percent. For the *risk- taking channel* that usually follows

[21] The function satisfies the following property. For those with positive threshold ($\phi_2 > 0$), $\Psi_y^{'}(x) > 0, \Psi_y^{''}(x) > 0$ if $x > \bar{x}$, while $\Psi_y(x) = 0$ if $x < \bar{x}$. For those with negative threshold ($\phi_2 < 0$), $\Psi_y^{'}(x) < 0, \Psi_y^{''}(x) < 0$ if $x < \bar{x}$, while $\Psi_y(x) = 0$ if $x > \bar{x}$.

Table 3: Nonlinearity Parameter Calibration

| Variable | Description | Parameter Value | | | | | Threshold |
|---|---|---|---|---|---|---|---|
| | | $\phi_1$ | $\phi_2$ | $\phi_3$ | $\phi_4$ | $\phi_5$ | |
| $\Psi_y(cred\hat{i}tgdp_t)$ | Debt Burden | $\frac{0.03}{100}$ | 2 | 0 | 1 | $\frac{1}{4}$ | $cred\hat{i}tgdp_t \geq 160\%$ |
| $\Psi_y(\Delta s_t)$ | Large E/R appreciation | $\frac{1}{375}$ | 2 | -12 | 1 | $\frac{1}{4}$ | $\Delta s_t \geq 6\%$ |
| $\Psi_{cred}(n\hat{p}l_t)$ | Credit crunch | $\frac{0.5}{100}$ | 2 | -20 | 1 | $\frac{1}{4}$ | $n\hat{p}l_t \geq 10\%$ |
| $\Psi_{npl}(\hat{y}_t)$ | Widespread Default | $\frac{5}{100}$ | -0.4 | -5 | 21 | - | $\hat{y}_t \leq -7\%$ |
| $\Psi_{npl}(i'_{t-1})$ | Risk-taking | $\frac{1}{4}$ | -3 | 2.5 | 1 | $\frac{1}{4}$ | $i'_{t-1} \leq 1.5\%$ |
| $\Psi_{TP}(debt_t)$ | Term Premium | $\frac{1.5}{80}$ | 2 | -120 | 1 | $\frac{1}{4}$ | $debt_t \geq 60\%$ |

Note: For widespread default and risk-taking channels, their nonlinear function has an upper limit to ensure reasonable dynamics at the tail of distribution.

the episode of low-for-long interest rates, we set $\bar{i'} = 1.5$ percent. Lastly, the *term premium channel* precipitates a sharp spike in 5-year government bond yields, as public debt-to-GDP ratios rise above a certain threshold. We specify $\bar{debt}$ at the Ministry of Finance's sustainable debt limit of 60 percent. The fiscal stimulus in response to the COVID-19 pandemic has rendered the public debt close to breaching the debt limit.

# 4 Model Property

This section illustrates the quantitative dynamics of the estimated model. In the first subsection, we show impulse responses to key shocks, with special attention given to roles of the financial sector in shock propagation. Then, we employ the model in simulating forecasts of key macroeconomic and financial variables in the wake of COVID-19. In particular, we show how an ELB imposes a stabilization constraint on the economy, necessitating integration of other policy tools. Finally, to evaluate risks and uncertainties ahead, we simulate the distribution of future economic activity, which will be a useful starting point in conducting policy analyses to tame tail risks, particularly those associated with financial instability.

## 4.1 Impulse Response Functions

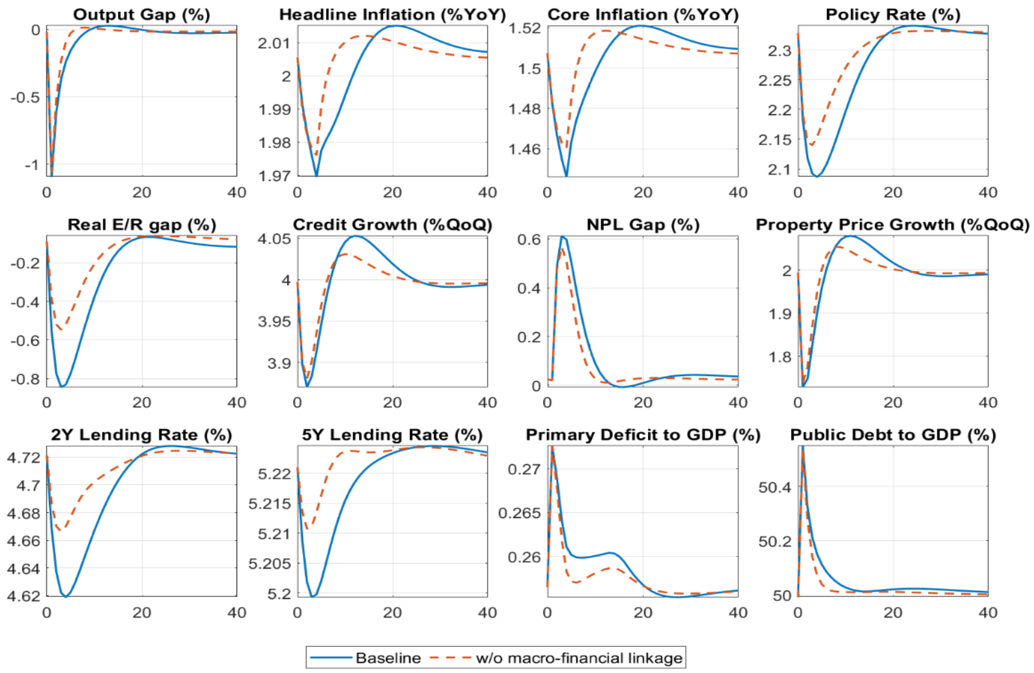
### 4.1.1 Output and Monetary Policy Shocks, and the Feedback Loop

Our goal here is to demonstrate the quantitative significance of the financial sector in shock propagation by examining the economy's responses to traditional macroeconomic shocks. Therefore, we depict impulse response functions for (1) the baseline model, which allows for macro-financial feedback loops, and (2) the model which macro-financial feedback loops are blocked through the finance-related parameters in the IS equation, i.e., setting $\beta_{cred} = \beta_{npl} = 0$.

First, a negative shock to an output gap, intended to capture adverse demand shocks, leads to declines in both output and inflation (Figure 2). In our baseline model, falling output depresses credit growth and raises NPLs, both of which further weigh on economic activity. Aside from their direct effects through the IS equation, the heightened NPLs impact the economy by increasing credit risks, which results in more tightened credit standards. Such responses of output gaps and inflation call for monetary accommodation, which then causes a temporary currency depreciation as well as drives down the loans interest rate. Monetary easing helps return both output and inflation towards their steady state. The IRFs show non-trivial macro-financial feedback effects. That is, output and inflation shortfalls in our baseline model are more pronounced than in the model without feedback loops, calling for a stronger reaction from monetary policy. Our model, hence, possesses a financial accelerator that reinforces and lengthens the model dynamics. In both cases, we note that fiscal policy also responds by adding more stimulus.

Examining responses to an adjustment in the policy rate can give a sense of how the impact of monetary policy is transmitted throughout the economy. From Figure 3, a one-percentage-point cut in the policy rate has expansionary effects, albeit rather small, on both economic activity and inflation. Monetary policy transmissions work through several channels. Aside for the traditional interest rate channel inducing intertemporal substitutions, we can identify exchange rate, credit and asset price channels. An exchange rate temporarily depreciates in line with the UIP condition. With the existence of a

Figure 2: Impulse Responses to a Domestic Output Shock



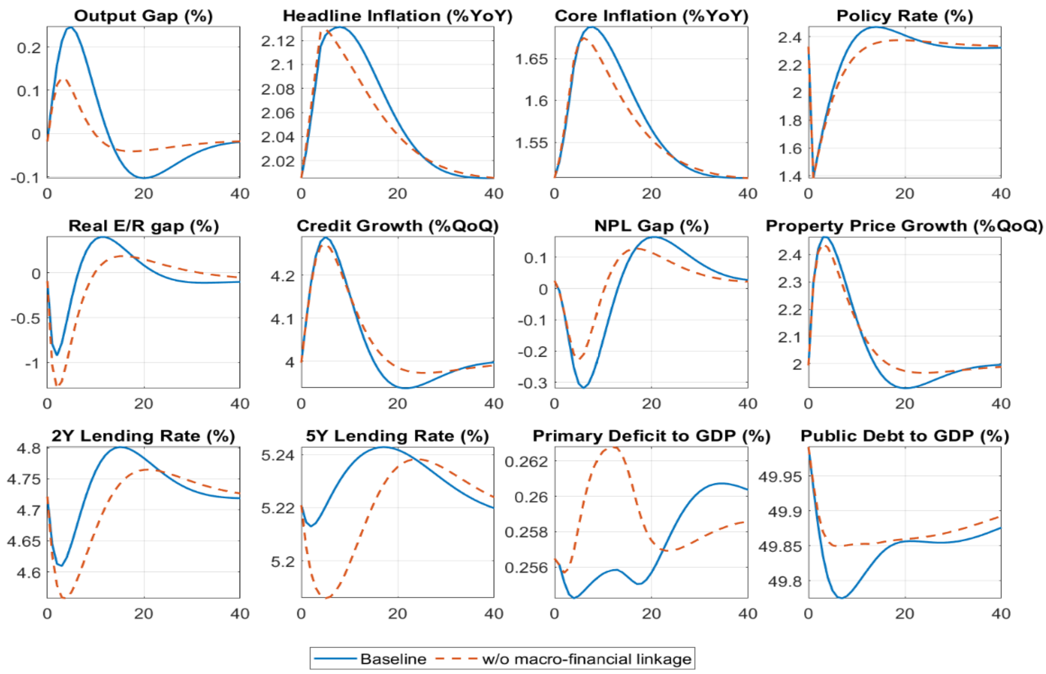

Note: the figure shows responses of the economy to a one-percentage-point shock to the domestic output gaps. Baseline responses are generated from the model with macro-financial linkages, while the w/o macro-financial linkage case assumes away the impact of credit growth and an NPL gap on the output gap.

financial sector, expansionary effects of rate cuts are amplified by an increase in credit growth and a fall in NPLs. Both lending rates, 2 and 5 years, reflect such declining credit risks and further ease financial conditions. In addition, property prices also rise, thus contributing to a credit-house price spiral, which helps sustain the economic expansion. Similar to the previous case, the policy impact are, therefore, clearly more persistent in the model with macro-financial linkages.

#### 4.1.2 Shocks Originated from the Financial Sector

In light of the 2008-09 Global Financial Crisis, financial shocks are regarded as an important source of macroeconomic fluctuations. Our model permits a large number of financial shocks, where we examine here shocks to credit growth and NPLs. Innovations to credit growth may result from changes in lenders' risk attitude shifting their incentives to supply loans. In the context of policy integration, they provide us channels to analyze the impact of credit-related measures, e.g. liquidity support program and macropruden-

Figure 3: Impulse Responses to an Expansionary Monetary Policy Shock

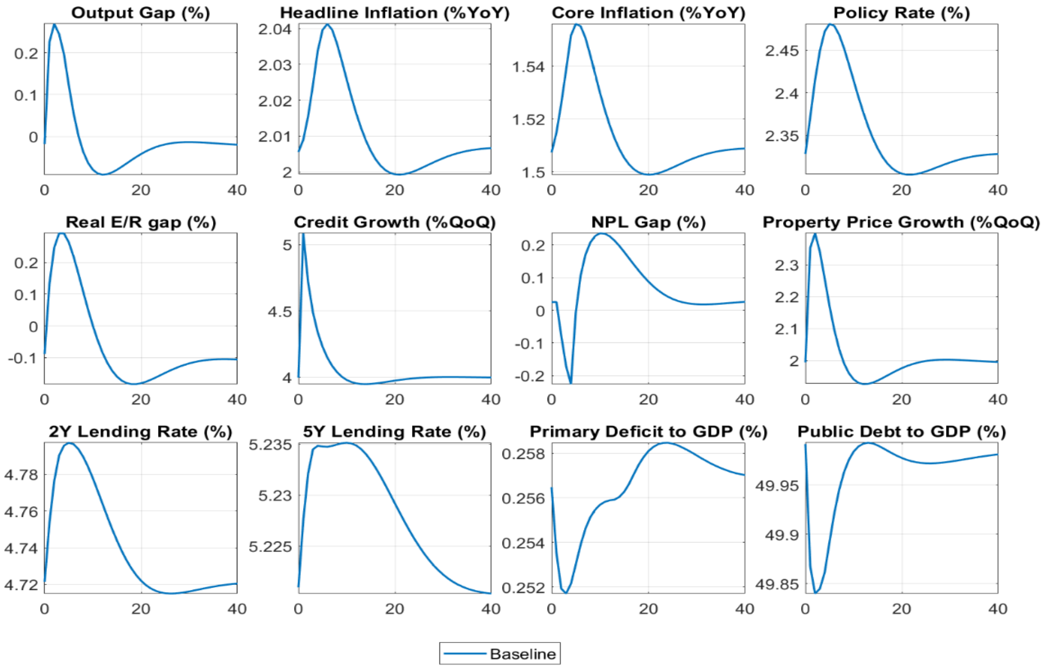



Note: the figure shows responses of the economy to a one-percentage-point shock to the policy rate. Baseline responses are generated from the model with macro-financial linkages, while the w/o macro-financial linkage case assumes away the impact of credit growth and an NPL gap on the output gap.

tial regulations. As shown in Figure 4, a one-percentage-point increase in credit growth brings about a significant rise in both an output gap and inflation. The output gap peaks at around 0.3 percent in a few quarters after a shock. Moreover, such credit expansion drives up property prices, which in turn relax collateral constraints. The policy rate rises, while a primary deficit contracts, in order to stabilize such credit-induced economic booms. Developments of credit risks are also worth-mentioning. NPLs fall in the first few periods thanks to an improvement in the private sector's balance sheets, bolstered by economic growth. However, NPLs increase over the medium term, dampening economic activity. Our model, hence, captures intertemporal trade-offs between a short-run credit expansion and longer-run greater credit risks.

An unexpected increase in NPLs, meanwhile, drives down the economy's output both directly and though the rise in credit risk premiums, which in turn causes a reduction in credit growth. Incorporating the non-linear property of credit activity responses to NPLs makes the economy susceptible to large NPL shocks. From Figure 5, we simulate three NPL shocks of different size, 5 10 and 15 percentage points. We can observe disproportionate declines in credit and economic growth, as the economy encounters a

Figure 4: Impulse Responses to a Positive Credit Growth Shock



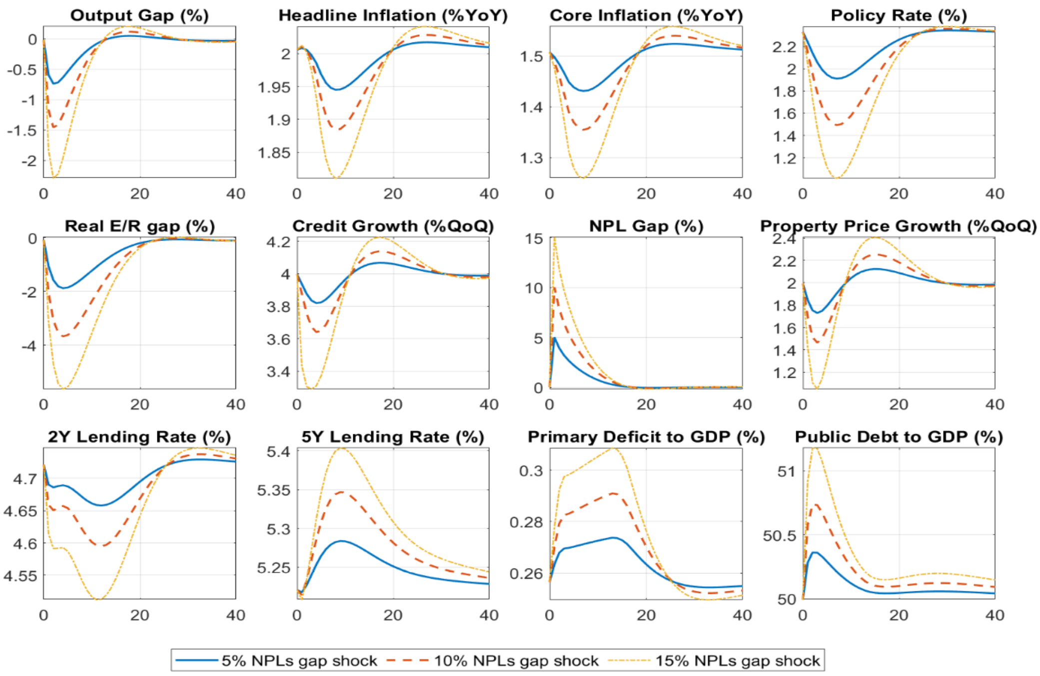

Note: the figure shows responses of the economy to a one-percentage-point shock to credit growth.

larger NPL shock. This finding arises naturally due to the calibration of $\Psi_{cred}(\hat{npl}_t)$, which defines the threshold of NPL gaps at 10 percent. Moreover, the interplay between 'credit crunch' and 'widespread default' worsens economic conditions in times of large shocks. The monetary policy rule then suggests the central bank a deep policy rate cut to cushion an economic downturn and offset significantly higher credit risk premiums facing the borrowers. Should an NPL shock become larger, the policy rate will likely be constrained by the ELB, which further exacerbates the shock impact. We will later show in the forecast simulation that movements of NPLs are useful in reflecting economic and financial crisis events.

### 4.1.3 Fiscal Policy Shock

Responses of a fiscal policy shock, represented here as shocks to the ratio of primary deficit to GDP, capture an intertemporal aspect of fiscal stimulus (Figure 6). In the short run, a larger primary deficit boosts economic activity and inflation, prompting the central bank to tighten their monetary policy. Nevertheless, such stimulus comes with a cost in terms of higher public debt. According the fiscal policy reaction function, an

Figure 5: Impulse Responses to Adverse NPL Shocks



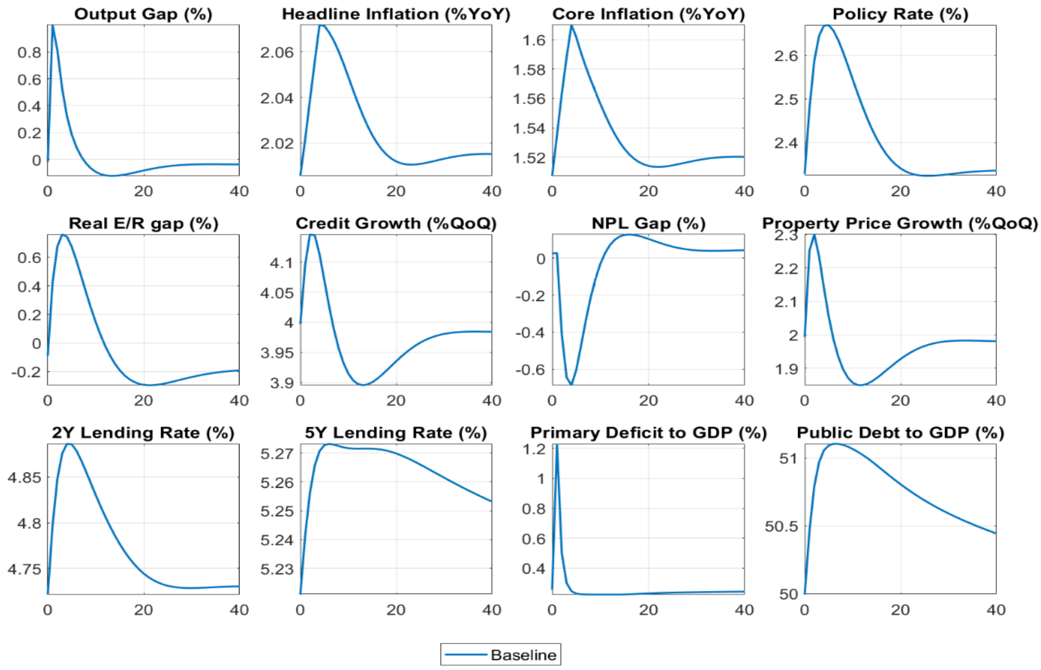

Note: blue, orange and yellow lines represent responses of the economy to five, ten, and fifteen-percentage-point positive shocks to an NPL gap, respectively.

increase in debt forces the government to reduce a budget deficit to lower its debt. Such a tightening action sends the output gaps somewhat negative in later periods. In addition, the heightened public debt level raises a term premium on government bond yields as well as a country risk premium that depreciates the currency value. The net 'indirect' impact from rising premium on the economy depends on which channel dominates. We note that if public debt becomes excessive, it could trigger a disproportionate rise in term premium, which stresses overall financial conditions. The negative impact from the 'term premium' channel will likely outweigh the positive impact from depreciations in such a case.

## 4.2 Conditional Forecast

Having examined the model's impulse responses, we use our model to perform economic forecasting in the aftermath of the COVID-19 pandemic. The forecasts will be conditional in the sense that we rely on the forecast path of a few variables from the Bank

Figure 6: Impulse Responses to an Expansionary Fiscal Policy Shock




Note: the figure shows responses of the economy to a one-percentage-point shock to the primary deficit-to-GDP ratio.

of Thailand's Macroeconomic Model (BOTMM) until end of 2023.[22] For most variables, the forecasts start from the second quarter of 2021. The assumptions underlying our baseline scenario are as follows. First, the effective lower bound on the policy rate is at 0.5 percent, its lowest level in history. The Bank of Thailand's several financial measures are also in place, including the soft loan facility for SMEs, totaling 250 billion baht, and the implementation of regulatory forbearance towards end of 2021 and the debt payment holiday, both of which help contain the rise in NPLs. In the next section, we will examine the extent to which these financial measures support Thai economic recovery. In addition, as pointed out in Section 3.1, the steady state of the economy during post-COVID may differ from the past, as the economy has experienced a deep and prolonged recession. For example, relying on expert judgment, we anticipate lower potential growth for both Thailand and trading partners, declining growth of credit and asset prices, but a higher public debt to GDP ratio and growth in NPLs. Moreover, we believe that Thai inflation

[22]These variables include real GDP growth, core inflation and trading partners' real GDP growth. We make slight adjustments to these forecasts for the sake of better illustration. In addition, as our model predicts rather large negative exchange rate gaps thanks to a slower pace of monetary policy normalization compared against the trading partners, we purposely tune their path throughout the entire forecast horizon. The baht begins to appreciate at end of 2022, as the current account balance rises.

will remain low given structural changes, e.g., from technological advancements. Please refer to Table 1.

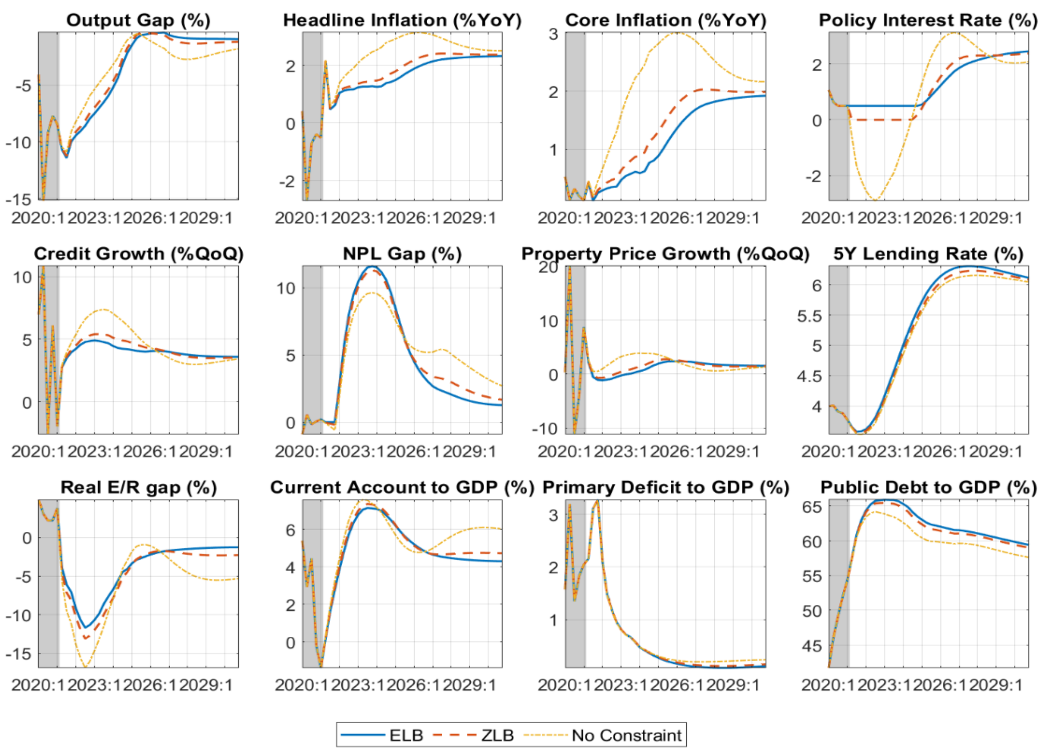
Figure 7 shows the forecasting results. Our baseline projection (blue lines) suggests that the Thai economy, as measured by the output gap, will gradually recover from the crisis. The output gaps almost close in 2026, but remain slightly negative onward given the private sector debt overhang that continues to weigh on consumption and investment. Core inflation also gradually rises toward the steady state in line with a slow economic recovery. The policy rate stays low for long, and only begins to normalize in 2025. Credit growth, meanwhile, is well above its post-COVID steady state, in part thanks to the central bank's support. However, due to the 'widespread default' channel, we observe a significant increase in NPLs from 2022 onward, as the economy still operates much below potential over such periods and financial measures are no longer in place. This could derail economic recovery to some extent.

We, next, conduct the first policy simulation to examine the relevance of ELB constraint. Specifically, we compare projections under 3 different scenarios: 1) the baseline case where the policy rate is constrained at 0.5 percent 2) the case where an ELB is at 0 percent (i.e., zero lower bound or ZLB) and 3) the case where negative policy rates are plausible (i.e., no ELB). The results show that in the first scenario (ELB=0.5), where conventional monetary policy is the most constrained, the model predicts the economy to grow below its potential for extended periods. Developments in the financial sector also suggest a more negative outlook, compared against the other two scenarios. Given such economic growth developments, the policy rate has to remain low for longer to provide a necessary stimulus, taking more time to reach its neutral level.

Other scenarios suggest a faster pace of economic recovery. In the ZLB scenario, the central bank can afford a slight, further monetary policy accommodation compared to the baseline. The policy rate is, therefore, abruptly cut to zero. With this extra boost, the economy would recover slightly faster. Policy rate normalization in this case, as expected, takes shorter periods. Meanwhile, in the no-ELB scenario, the model suggests the central bank should cut the policy rate to as low as -2.5 percent, prompting the output gap to close four-quarter earlier than in our baseline scenario. We also observe both a greater credit extension and a fewer increase in NPLs, and so lessening the adverse feedback effects from the financial sector. The economy, therefore, can achieve the fastest recovery among three scenarios. However, given interest rate persistence, it would take some time for the policy rate to adjust toward its steady-state neutral level. That said, it is worth mentioning the intertemporal trade-offs, as near-term eased financial conditions fuel a credit expansion and aggravate the 'debt burden' and 'risk-taking' channels, which later cause a contraction in financial and economic activity in the longer run.

In sum, comparison of the three scenarios has highlighted consequences of a policy constraint under the ELB, at times the economy encounters large, adverse economic shocks. The policy constraint necessitates the roles of policy integration to explore over the next section.

Figure 7: Conditional Forecast




Note: forecasts begin from 2021Q2. Blue and orange lines show forecasts assuming the effective lower bound at 0.5 and 0 percent, respectively. Meanwhile, yellow dotted lines show forecasts when there is no constraint on monetary policy.

### 4.2.1 GDP at Risk

Analyzing central projections alone becomes inadequate, given the large degree of risks and uncertainties facing the economy especially in crisis times. In this subsection, we attempt to quantify these risks by computing the distribution of future output gap and other variables of interest along our baseline forecast path. We do so through simulations by randomizing key macro-financial shocks[23] from their respective distributions (normal distribution with zero mean and estimated standard deviations) during the forecast horizon. We perform a total 1000 simulations, each of which is initialized at the model's baseline scenario above. This allows us to produce the confidence band along the forecast path, which resembles a fan chart typically used by the central bank to communicate imminent risks and uncertainties. Our goal here is to illustrate the importance of the model's nonlinearities in generating macroeconomic tail events, or the 'GDP at risk'. Given that our model features extensive real-financial sector linkages, such tail risks naturally inform us the development of macroeconomic risks associated with financial vulnerabilities.

Figure 8 shows the forecasted conditional distribution of certain variables. The black line represents the median path, while the darker shades represent the most likely 40 percent of the distribution, and the lighter shades the most likely 90 percent.[24] The lower bound of the output gap distribution, the so-called 5% GDP-at-Risk, informs policymakers about a tail or crisis outcome. In addition, we further show the significance of nonlinearity by plotting the 90-percent confidence band simulated from the linear model, shown in the figure as red dashed lines.

Comparing to the red lines of the linear model, we observe the largest shift in distribution at the left tail for the output gap, but a relatively smaller shift at the higher percentiles. This shift implies that the GDP distribution is fat-tailed, particularly in the short run. This may not be surprising, since the economy's initial conditions are already in the stressful state where several nonlinear dynamics are triggered and remain so into the near future. First, in the face of COVID-19, the policy rate is already at its ELB, constraining the ability to further ease monetary policy if more negative shocks occur. The interplay between the 'widespread default' and 'credit crunch' channels should also become more intense if downside risks to growth materialize. That is, lower output leads to higher NPLs; higher NPLs results in a credit crunch; a credit crunch further lowers output. The conditional distribution of NPLs and credit growth, which is much more

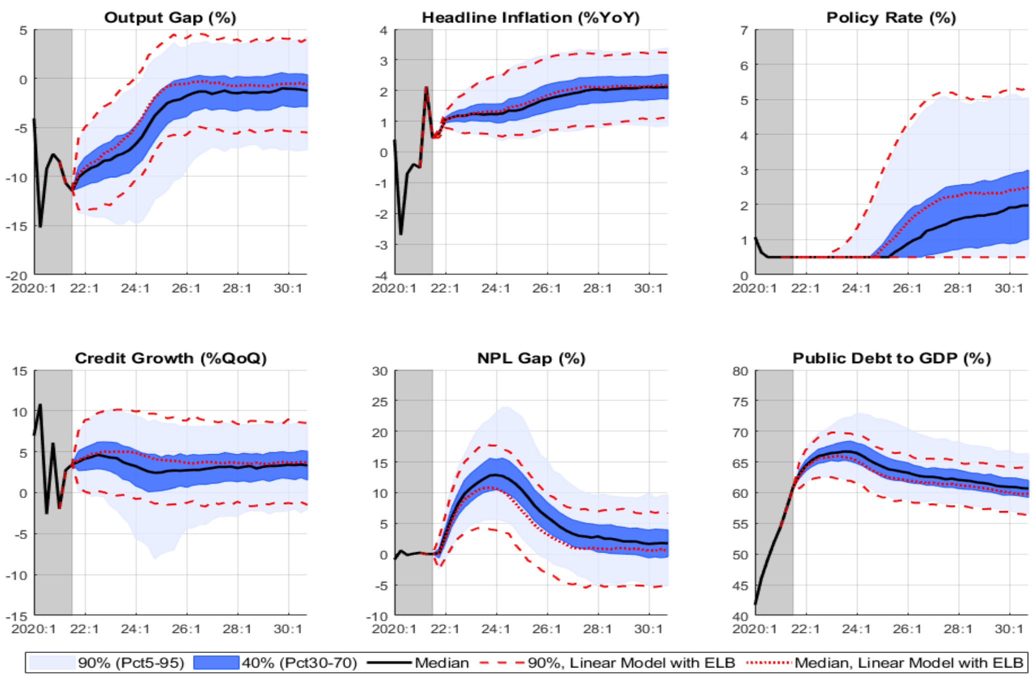
[23] These include $\epsilon_t^y$, $\epsilon_t^\pi$, $\epsilon_t^s$, $\epsilon_t^{npl}$, and $\epsilon_t^{cred}$.

[24] The corresponding lower and upper bounds are $25^{th}$ ($5^{th}$) and the $75^{th}$ ($95^{th}$) percentiles for darker (lighter) shades.

skewed than that in the linear model, helps validate this claim.[25] In addition, as private sector debt is already at a high level prior to the COVID-19 episode, this adds another nonlinear channel that impairs growth dynamics, particular when adverse shocks lead to an additional rise in the ratio of private sector debt to GDP. These mechanisms, which lie in the model's macro-financial linkages, create the fatter left tail in the GDP distribution in our nonlinear model.

Over the medium run, as the output gap recovers back toward steady state, we observe that the effects of these constraints and nonlinearities subside. That said, certain nonlinear channels will still be at play at the downside tail, especially the impact of the low-for-long policy rate on credit quality and the on-going 'debt burden' channel. The forecasted conditional distribution in Figure 8, therefore, provides us a useful baseline scenario for conducting policy analyses, as policymakers aim to improve macroeconomic outcomes by focusing on the entire GDP distribution over the short and medium term.

Figure 8: Distributional Forecast




Note: fan charts illustrate the forecasting distribution for the baseline case, assuming the effective lower bound at 0.5 percent. The black line represents the median projection while the dark blue and light blue areas represent 40% and 90% probability that the economic outcomes will likely fall in the regions. The red dashed lines represent 90% probability from the model without nonlinearities.

[25]Another interesting finding is that the forecasted distribution for inflation does not exhibit skewness and fat tail, compared against other variables. This result is in line with Adrian et al. (2020a) and may be owing to the flattening of Phillips curve.

# 5 Integrated Policy Analysis: Some Applications

In this section, we apply our model to shed light on potential gains from policy integration. The analyses center on key economic challenges facing the Thai economy and the central bank in the aftermath of the COVID-19 pandemic. The first ongoing challenge is how to foster robust economic recovery and stabilize growth, with the traditional policy rate approaching the lower bound and facing weak transmissions to credit and economic activity. On the financial-stability front, the high household debt that has already been in a fragile position prior to the COVID-19 outburst, is exacerbated by pandemic-induced income shocks. These two challenges result in key policy trade-offs between fostering sustainable household debt levels and stabilizing economic growth. Moreover, in light of volatile capital flows, Thai financial markets are subject to large exchange rate volatility, which could derail smooth economic recovery.

With these three challenges in mind, we apply our model to three counterfactual policy analyses. First, focusing on the episode of economic recovery, we show that several financial measures in place are supportive to a near-term economic expansion by precluding adverse real-financial feedback loops and the associated nonlinearities. In light of imminent risks from exchange rate volatility, we also study how active FX intervention ensures a better macroeconomic outcome. In the second application, we illustrate how the interaction between monetary and macroprudential policies helps address financial stability risks from high household debt, and improves intertemporal trade-offs facing monetary policymakers. Third, given a constraint on monetary policy, we analyze roles of fiscal policy toward economic recovery, and its interaction with monetary policy. On the whole, we will highlight that policy integration could yield a better macroeconomic outcome by preventing nonlinearities, improving policy trade-offs, and ensuring sufficient stabilization in times of constrained policies.

## 5.1 Fostering Economic Recovery

### 5.1.1 Roles of Financial Measures

The Bank of Thailand has responded with a swift and forceful action to a pandemic-induced economic crisis, which dragged the GDP growth in the second quarter of 2020 to as low as 12.2 percent and is followed by slow recovery towards potential. Aside from policy rate cuts, the Bank has implemented several financial measures to alleviate economic and financial shortfalls. As discussed in Section 4.2, our baseline projection has factored in some of these measures. There are (1) soft loans for SMEs; (2) regulatory forbearance and loans payment holiday, which help mitigate the rise in NPLs toward end-2021.[26]

To quantify the impact of financial measures in supporting an economic recovery, we perform a counterfactual analysis by examining what would happen should these measures were not implemented. Figure 9 considers the counterfactual case without both measures, and compares it to the baseline scenario shown in Figure 7 above. To purge the financial-measure impact of the forecast, for regulatory forbearance, we use the Kalman filter to identify shocks underlying our conditional forecast path. We postulate that shocks to NPL gaps during 2021 are entirely a result of such measure, and nullify them. Meanwhile, for a soft loans measure, the forecast of private credit growth is deducted by the total amount of soft loans available in the facility, i.e., 250 billion baht spread out over 2021-2022.

By preventing nonlinearities associated with NPLs and credit extension, which could exacerbate economic activity, the financial measures are proven vital in supporting economic recovery and lessening large, downside risks to the economy. In Figure 9, we observe that without both measures NPLs would skyrocket to around 17 percent in 2023, much higher than in the baseline. This is mainly attributed to the nonlinear 'widespread

[26]Soft loan facility is part of the Financial Rehabilitation measures, launched in March 2021. The facility offers funding for financial institutions at low rate to channel liquidity to business in need. A credit guarantee scheme through the Thai Credit Guarantee Corporation (TCG) supports the facility. Meanwhile, regulatory forbearance is referred to the measure that retains the classification of debtors who engage in preemptive debt restructuring. Those measures focusing on debt payment moratorium, e.g. minimum assistance measures and debt holiday for SMEs, also yield similar benefits in terms of curtailing NPL risks.

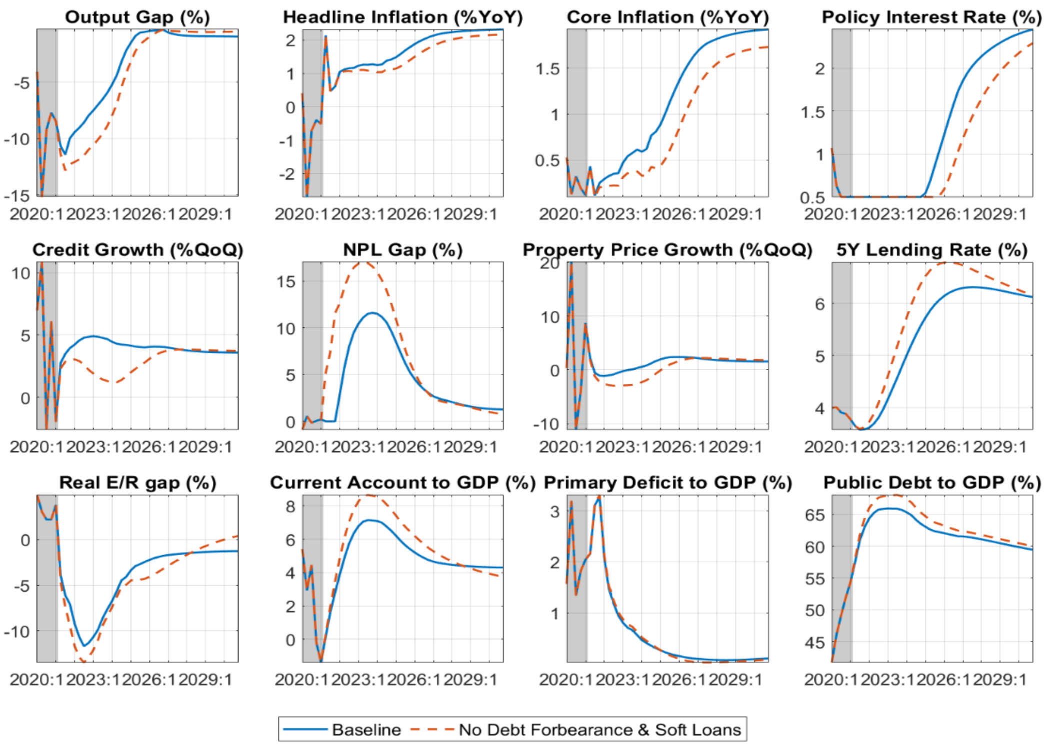
default' channel, as economic activity operates significantly below its potential. Increased NPLs would next trigger a 'credit crunch', i.e., disproportionately lead to a greater decline in credit growth. Without support from a soft loans measure, the credit growth outlook would look much worse. Both worsened credit growth and rising NPLs, in turn, exacerbated an economic downturn, thereby triggering the complete adverse feedback loops. We can clearly see that an economic recession would become significantly deeper and more extended, prompting the policy rate to stay low for longer. Despite more accommodative monetary policy, it is not enough to offset the higher lending rates triggered by increased credit risks.

Figure 10 further shows greater downside risks and severe tail events for the no-measure case. The outlook for output gaps and credit growth are much more tilted to the downside, and that for NPLs to the upside. At the tail, the peak of an NPLs gap is as large as 30 percent, compared against 25 percent in our baseline. The result points to a stronger nonlinearity mechanism as downside risks materialize. And, due to the 'risk-taking' channel, that the policy rate must be kept low for longer as an economic crisis lingers could also worsen credit quality and exacerbate the downturn in the longer run. The outlook for the public debt is also worth-mentioning. Deep economic recessions at the tail could send the ratio of public debt to GDP to as high as 80 percent, which triggers nonlinear increases in term premiums. These results, therefore, underscore the necessity of financial measures in complementing the constrained interest rate policy, being a more targeted tool that directly addresses the nonlinearity problem. Importantly, they help preclude a more severe economic crisis, which would otherwise call for aggressive but implausible monetary policy actions.

#### 5.1.2 FX Intervention to Address Exchange Rate Volatility

Having explored the financial measures already in place, we next explore the effectiveness of another frequently-used tool, the FX intervention, in supporting economic recovery going forward. To prevent exchange rates from being too volatile, the Bank of Thailand occasionally intervenes in the FX markets. Given negative output gaps, the economy stands to benefit from the intervention to prevent a sharp exchange rate appreciation,

Figure 9: Conditional Forecast: without Soft Loans and Regulatory Forbearance



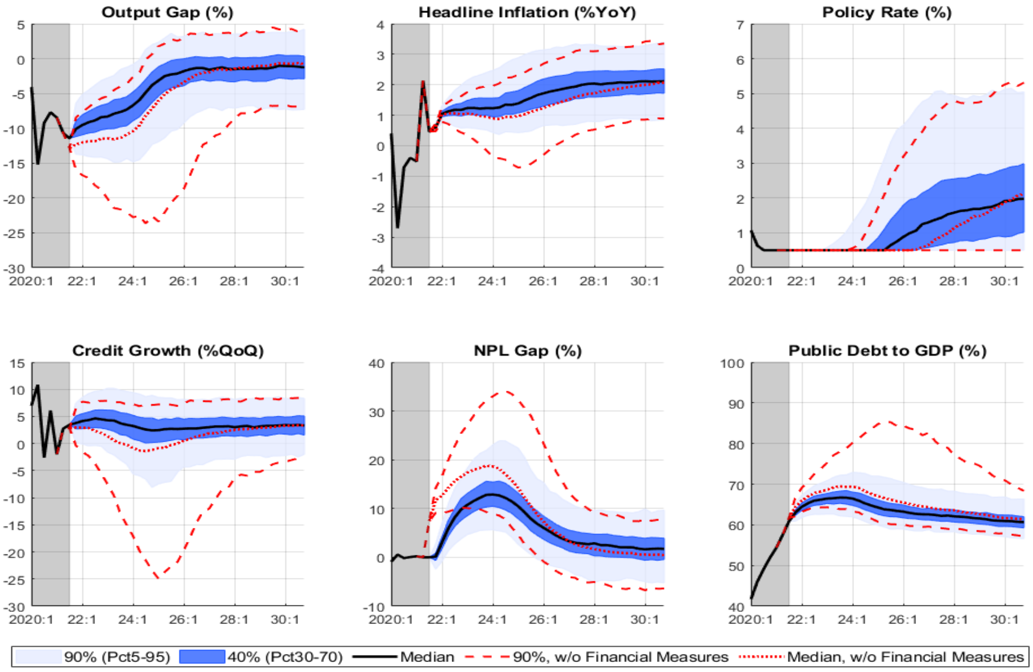

Note: forecasts begin from 2021Q2. The orange dashed lines represent the case where there were no financial measures, by assuming shocks to the NPL gap during 2021 to be zero and by deducting the amount of soft loans from credit growth path. We assume the policy rate is constrained at 0.5 percent. The blue lines show conditional forecasts from the baseline scenario.

which could exert a nonlinear consequence and worsen the recovery.[27] To depict the episode of sharp appreciation, we assume stronger baht appreciation from end-2022 to end-2025, almost doubling the size of changes in nominal exchange rates occurred in our baseline's central projection. The maximum strengthening is around 10 percent annually, which is a plausible assumption according to past data. Despite a persistent appreciation, the real exchange rate gap is marginally positive. After 2025, baht depreciation follows to close the gap. Moreover, we also consider a further case where the central bank deviates from the intervention rule prescribed above and intervenes to slow down the pace of appreciation.

Figure 11 shows economic projections for the three cases: (1) our baseline, (2) a sharp appreciation episode and, (3) a sharp appreciation with an active FX interven-

[27]Unlike other EMEs, exchange rate depreciations in Thailand's context mainly benefit economic conditions, particularly exporters. The low external debt and limited foreign participation in local-currency securities preclude the 'financial channel' of exchange rates that links capital movements to domestic financial conditions. At the same time, the low exchange rate pass-through to domestic prices limits risks to inflation.

Figure 10: Distributional Forecast: without Soft Loans and Regulatory Forbearance




Note: fan charts illustrate the forecasting distribution from the baseline scenario. Red dashed lines show 90% probability of the likely outcomes from the case, where there were no financial measures, by assuming shocks to the NPL gap during 2021 to be zero and by deducting the amount of soft loans from credit growth path.

tion. The results show that the episode of large domestic currency strengthening can significantly drag down the output gaps and inflation. This causes a further delay in economic recovery, and the policy rate normalization. The nonlinearity associated with sharp appreciation during an economic downturn contributes to the exchange rate impact and justifies further intervention. The active intervention case shows the benefit of such weakening-bias strategy, especially by preventing such nonlinear exchange rate impact. Given the improved growth and inflation outturn, policy rate normalization could occur slightly faster. In Figure 12, we show distributions for future output gaps and inflation to illustrate how the latter two cases affect at-risk outcomes. We, however, observe that the active FX intervention yields only a slight improvement in tail GDP and inflation downside risks. This might be because exchange rate shocks are not the main source of tail events.[28]

[28] Another source of financial market volatility might arise from the QE tapering that potentially leads to the spike of yield curve and a tightening of domestic financial conditions. This model permits this channel and the associated policy responses through term premiums. In an earlier version of this paper, we analyzed the benefit of yield curve control (YCC), which is often among the unconventional policy toolkit employed by advanced economies.

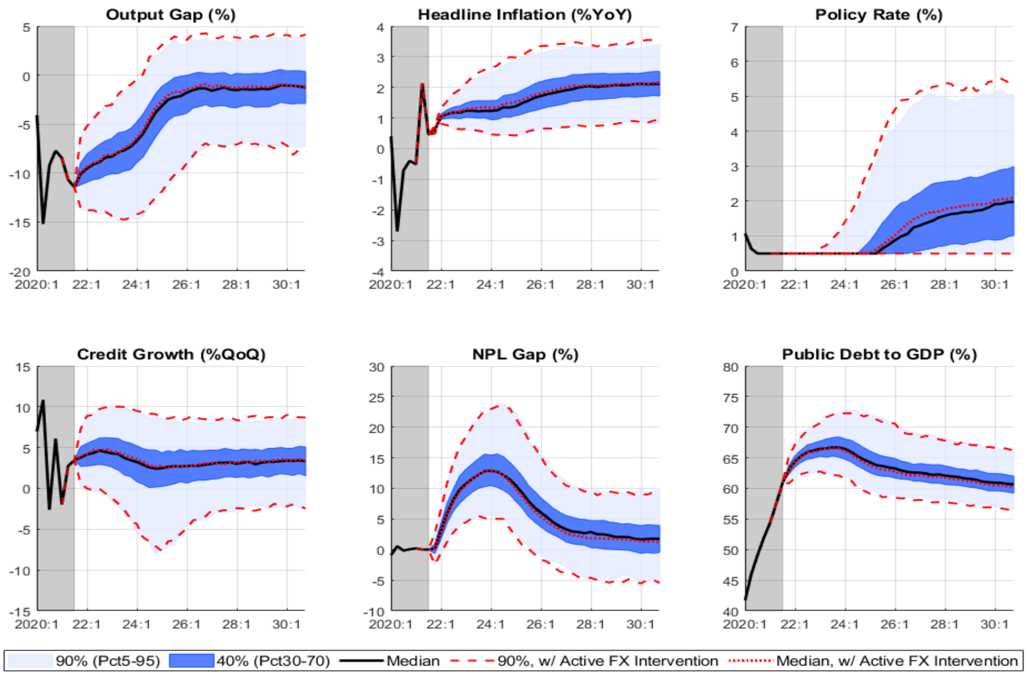
Figure 11: Conditional Forecast: with Sharp Appreciation and Active FX Intervention


Note: forecasts begin from 2021Q2. Three scenarios are considered. The first scenario (blue lines) is the baseline while the second one (orange dashed lines) illustrates the sharp appreciation scenario, assuming the central bank following the FX intervention rule. In the last case (dotted yellow lines), we consider the active FX intervention to slow the pace of appreciation, assuming the central bank's purchases of foreign exchange around 6 percent to GDP during the appreciation episode.

## 5.2 Interaction between Monetary and Macroprudential Policy to Address High Debt

In the second application, we consider a longer-term policy challenge, the integration of monetary and macroprudential policy in addressing financial stability risks. In particular, we are interested in the high household debt problem, which has become a structural issue for the Thai economy over the recent years. While debt facilitates current consumption, it, if excessive, results in a large debt burden, which weighs on future consumption. Concerns over households' debt serviceability also mount, posing financial stability risks. In the context of our model, excessive private sector debt exerts nonlinear negative effects on economic activity through the 'debt burden' channel. To curb household debt, the central bank faces trade-offs between [1] worsened near-term economic performance as policies act to constrain debt and [2] a better future outcome given the more stabilized debt level, a typical intertemporal trade-off facing the central bank seeking to mitigate

Figure 12: Distributional Forecast: with Sharp Appreciation and Active FX Intervention




Note: fan charts illustrate forecasting distributions in the case where the exchange rate appreciates sharply, assuming the central bank following the FX intervention rule. The black line represents the median projection, while the dark blue and light blue areas represent 40% and 90% probability that the economic outcomes will likely fall in the regions. Red dashed lines represent 90% probability of the likely outcomes as the central bank engages in the active FX intervention to slow the pace of appreciation.

financial stability risks. However, the toughest part lies in the fact the economy is already in recession, hence worsening such a policy trade-off.

We use the model to evaluate the effectiveness of two policy measures, including the policy rate and the credit control measure, in curbing household debt. In practice, the credit control measure may be equivalent to imposing limits on debt-servicing ratio or loan-to-value ratio, which constrains new flows of credit and debt. In the simulation, we endogenize negative shocks to credit growth such that the household's debt to GDP ratio follows the pre-determined path. This approach allows the central bank to gradually adjust debt to the targeted level. Meanwhile, when the central bank desires to use monetary policy tightening to lower debt, i.e. to lean against the wind, we assume that the central bank sets the policy rate around 25- or 50- basis points above the rate prescribed by the traditional monetary policy rule:

$$i_t^{taylor} = \rho_i i_{t-1}^{taylor} + (1-\rho_i)[\bar{r}_t + \pi_{yoy,t+4}^{cpi} + \phi_y \hat{y}_t + \phi_\pi(\pi_{yoy,t+4} - \pi^{target}] + \epsilon_t^{law} + \epsilon_t^i, \quad (37)$$

where $\epsilon_t^{law}$ captures such a lean-against-the-wind incentive.

As an indicator for household debt fragility, aside from credit-to-GDP ratios, we also monitor a debt service ratio, which measures the ability of household to use its income to repay all its debt obligations. We calculate debt service ratios ($dsr_t$) through the following formula:

$$dsr_t = \frac{cred_t^{hh} ilend_t^{5y}}{(1-(1+ilend_t^{5y})^{-mat}))y_t^{hh}}, \tag{38}$$

where $cred_t^{hh}$ is the stock of household debt, $mat$ is the average maturity of household debt outstanding and $y_t^{hh}$ denotes household income. We assume that $cred_t^{hh}$ grows at the same rate as overall private credit. Meanwhile, $mat$ is calibrated to be 20 quarters or 5 years. The duration associates with the fact that retail loans mainly consist of long-term personal loans and mortgages. Last, we obtain $y_t^{hh}$ by multiplying total output with the household income share from national income statistics.

The key focus is "the extent of the intertemporal trade-offs as the central bank attempts to control household debt". Note that, without any policy intervention, the $dsr_t$ and the ratio of private sector credit to GDP are expected to reach 58 and 177 percent in 2030, respectively. We consider two policy experiments: first, the central bank implements a credit control measure during 2022-2026, while relies upon the existing traditional monetary policy rule. As the economy is already under crisis, the timing of policy implementation is key. So, we assume that the central bank employs a backload strategy, while aiming to reduce household debt outstanding by approximately 2 trillion baht.[29] Second, the central bank instead uses monetary policy to lean against the wind by around 50 basis points. In each case, we mainly focus on the intertemporal trade-offs, i.e. their long-term benefits in reducing financial stability risks, especially the lower probability of tail events, to be compared against the short-term costs in terms of forgoing output and inflation.

Figure 13 shows the simulation results for the central projections, where the blue lines show baseline forecasts. The intertemporal trade-offs are evident in both policy exercises. Regarding monetary policy, the leaning against the wind strategy delays

[29] 160 billion baht a year during 2022-23, and 560 trillion baht a year during 2024-26. The Bank may, indeed, rely on other debt restructuring measures that are less contractionary, e.g. loans haircut, interest rate reduction, etc.

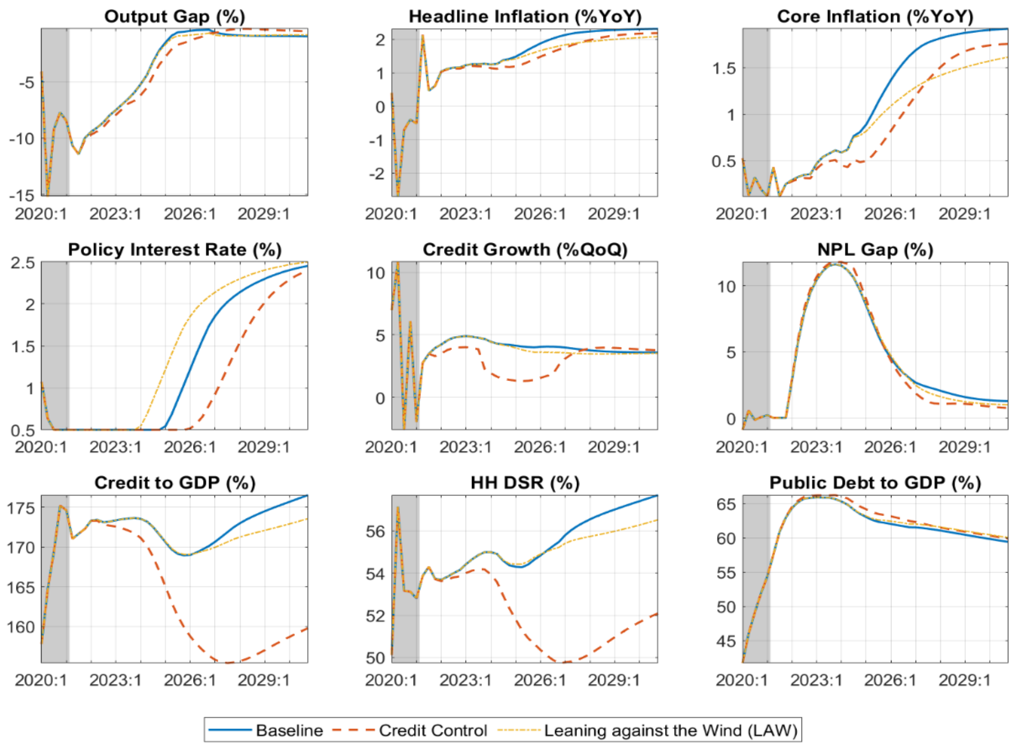
economic recovery to some extent and causes inflation to prevail lower than target for extended periods, however its benefit toward reducing household debt is small. In particular, its long-term benefit on the future path of economic activity can hardly be observed. This strategy, we consider, is rather ineffective and involves relatively large policy trade-offs. This confirms the fact that monetary policy can be a blunt instrument, exerting an economy-wide impact but not targeted enough to address specific financial stability risks. It is to note that the household's debt service ratio increases slightly in the short run potentially due to increased borrowing costs before wandering below baseline in the medium run. Credit restrictions, being a more targeted measure, improve the trade-offs. Although output gaps become significantly more negative during deleveraging periods, delaying the closing of the gaps, we achieve a massive reduction in household debt and $dsr_t$. Over the longer run (post-deleveraging periods), output gaps stay higher than baseline as a result, since the 'debt burden' effects no longer weigh on economic activity. Monetary policy in this case becomes more expansionary to cushion economic shortfalls induced by tightened prudential measures.[30]

An evaluation of the intertemporal trade-offs is better shown in Figure 14, where we show the output gap distributions during post-deleveraging periods (2030). This allows us to consider potential long-term gains in terms of the improved GDP at risk. Consistent with the above, the longer-term GDP distribution shifts rightward, after the implementation of credit growth control. The dissipating 'debt burden' effects result in the significantly lower downside tail risks. In particular, the probability of output gaps falling below -5 percent has substantially declined by around one-third, thereby limiting the future episode of financial crisis events. Long-term gains from imposing credit restrictions, hence, become more obvious as we focus on the policy impact on macro-financial risks. On the other hand, the lean-against-the-wind strategy shows a rather small impact on the future output gap distribution. That said, whether the central bank should implement these measures will be a challenging policy decision and depends on how it weighs these temporal gains and losses in practice. At least in the case of household debt deleveraging, our results provide some support for the use of macroprudential policy to complement monetary policy, which may otherwise be overburdened in dealing with

[30]While imposing credit restrictions yields better outcome, some believe that both monetary policy and macroprudential measures ought to be complementary. Conducting expansionary monetary policy amounts to pressing the accelerator, while credit control measures are pushing the brake (Borio (2016)).

financial stability issues. Monetary policy is thus given more degree of freedom to focus on its traditional objectives, i.e., to stabilize growth and prices.[31]

Figure 13: Conditional Forecast: Credit Control Measure and Leaning Against the Wind




Note: we evaluate two policy alternatives to address the high household debt. First, in orange dashed lines, the central bank resorts to credit restrictions. Second, in yellow dotted lines, monetary policy is employed to lean against the wind. We assume the central bank sets the policy rate above the level prescribed by the policy rule by 0.5 percentage point throughout forecasting periods. Blue lines show the baseline scenario, where forecasts begin from 2021.

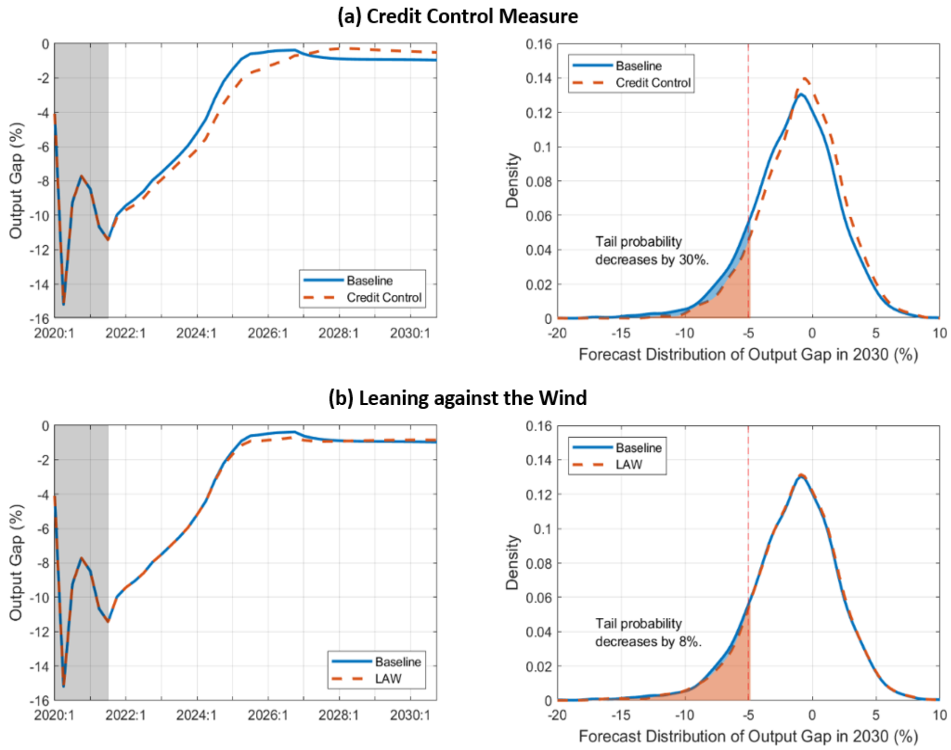
## 5.3 Roles of Fiscal Policy

Against the backdrop of constrained monetary policy, the coordination between fiscal and monetary policy has gained more attention. We witness an unprecedented level of fiscal stimulus, deployed to combat the recession. Although not part of the central bank toolkit, we add the fiscal block to address the larger role that fiscal policy will play in the next few years. We analyze whether fiscal policy could step in to complement other tools to achieve better overall economic outcomes.

In the scenario shown in Figure 15, we increase the primary deficit-to-GDP

[31] We note that in reality the devise of macroprudential measures can be subject to political and social pressures, and the implementation lag given their redistributive nature.

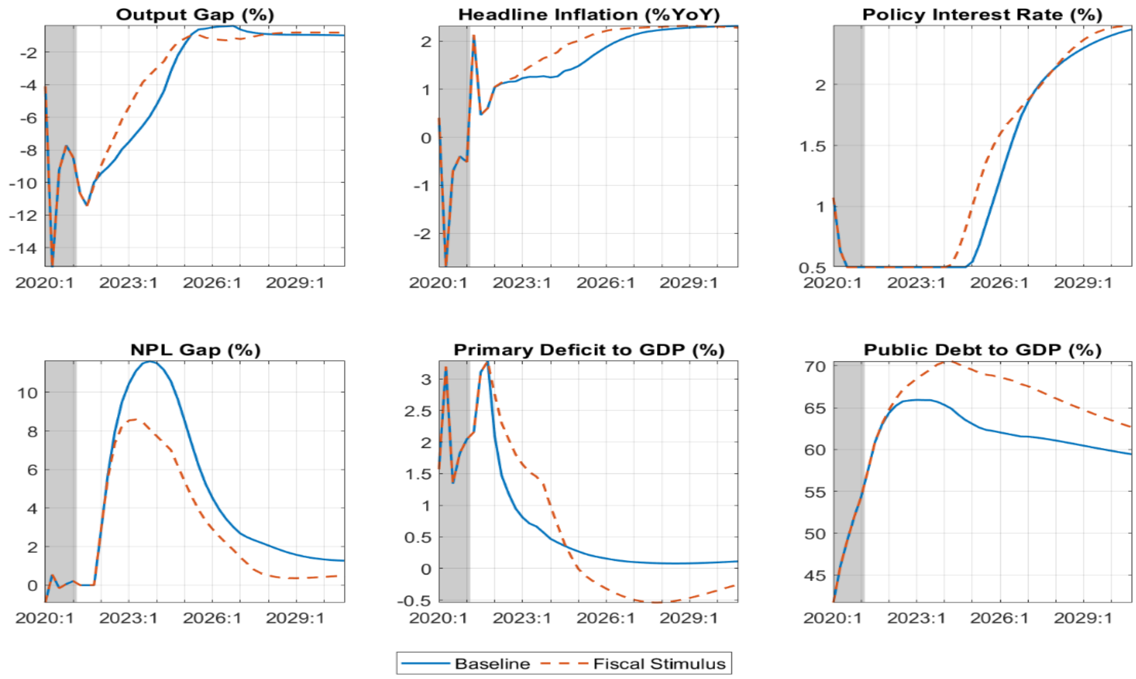
Figure 14: Policy Trade-offs from Implementing Policy to Reduce Household Debt




Note: the figure shows the short-term costs and long-term benefits from implementing two policy alternatives to address the high household debt: a credit control measure in Panel (a) and using monetary policy to lean against the wind in Panel (b). The left subfigure in each panel depicts the forecast path of output gaps. The right subfigure shows the forecasting distribution of output gaps in 2030, the baseline in blue lines and the deleveraging scenario in dashed orange lines.

ratio from baseline by an average of 1 percent over the next 3 years; the stimulus is slightly front-loaded and is most impactful in the first year starting in the first quarter of 2022. In this scenario, the public debt-to-GDP ratio would rise from 55 percent at the end of the second quarter in 2021 to its peak of 70% in 2024. The government spending provides a direct demand boost that increases the output gap by an average of 2% during the stimulus period and helps bring inflation back to its steady state. This allows for an earlier normalization of monetary policy. The time-dimension trade-off for this policy is clear; the benefits are realized in the shorter term, and the costs are realized later. The rising public debt increases government funding costs, and the primary balance has to decrease to bring the debt level back to its target. This is a drag to demand after the stimulus ends, as we can see that the output gap is lower than the baseline case after 2026. However, this may be more bearable and lead to a better overall economic outcome

Figure 15: Conditional Forecast: with Extra Fiscal Stimulus



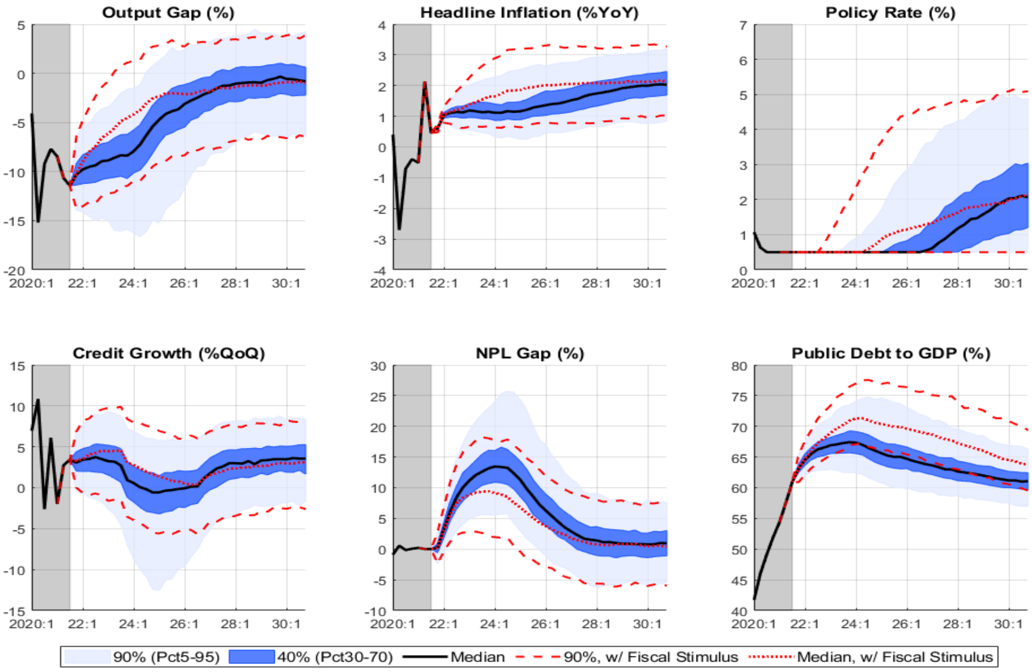

Note: this figure compares the baseline scenario (blue lines) to a scenario that assumes an extra government stimulus in 2022-2024 (dashed orange lines). Forecast begins from 2021.

as the output gap is much closer to zero at this point.[32]

The impact of the fiscal stimulus is even more apparent in the left tail of the GDP distribution, shown in Figure 16. Here we plot the confidence bands for both the baseline scenario and the case with an extra fiscal stimulus. The difference between the two confidence bands are largest in the left tails and during 2024-2026. The closing of the output gap when it is widest not only is more optimal from a quadratic loss function perspective, but also prevents the model's nonlinear dynamics from causing havoc on the economy. Higher growth decreases the possibility of NPL spiraling out of control, which consequently reduces the possibility of a credit crunch. The 90% confidence bands in Figure 16 is reflective of these decreased probabilities. The distributions are much more symmetrical than the baseline case. The household debt burden nonlinearity channel is also less likely to occur with higher income resulting from higher output growth. The lack of the aforementioned nonlinearities, in turn, makes the output gap distribution more symmetrical and results in higher values of the 'GDP-at-risk'.

[32]The simple central bank's loss function minimizes squared deviations of the output gap and inflation from their target. The square terms imply a lower net loss if we can make the trade-off of lowering the output gap when the level is higher and increasing when the level is small.

Figure 16: Distributional Forecast: with Extra Fiscal Stimulus




Note: fan charts in blue illustrate the forecasting distribution from the baseline scenario. The black line represents the median projection while the dark blue and light blue areas represent 40% and 90% probability that the economic outcomes will likely fall in the regions. Red dashed lines represent 90% probability of the likely outcomes from the scenario with an additional fiscal stimulus in 2022-2024.

To conclude, we find that fiscal policy can complement monetary policy and assist the central bank in the pursuit of their objectives. An aggressive fiscal policy during the COVID-19 recovery can yield benefits since it stimulates demand and reduces the output gap at its widest point. Not only that, the higher value of 'GDP-at-risk' also implies a lessened macro-financial tail risks, as the government stimulus mostly eliminates the nonlinearities originating from the financial block. The drawback, the future decreases in government spending as a result of higher public debt, is an acceptable trade-off as it occurs when the output gap is nearer to zero.

# 6 Concluding Remarks

To support the central bank's practice of using multiple policy tools, this paper improves Thailand's monetary policy model along several aspects. By embedding macro-financial linkages, we enable a feedback loop between real and financial sectors. Such inclusion of a financial sector also allows for an insightful examination of various policy tools that can complement conventional monetary policy. Nonlinearities also become an integral part of our model. By making the economy susceptible to large, adverse shocks, the model can well capture macroeconomic downside risks and tail events, which justify extra policy intervention to ward off the crisis. The model capacity is, therefore, enhanced to analyze a wide range of measures at the central banks' disposal. One of the important features is that the model can facilitate the evaluation of policy trade-offs from addressing financial stability issues, which are of intertemporal nature.

Our extended model offers a coherent framework for conducting integrated policy analyses in practice. It contributes to a systematic evaluation of policy impact and trade-offs, as well as provides us with insights regarding the interaction among policy tools. Ideally, it would recommend an analytical view on how best to combine these tools to achieve better economic outcomes. In this paper, we have shown three applications of the model against the backdrop of economic recovery from the COVID-19 pandemic. The first application assesses the impact of various policies in supporting the recovery, where we show the effectiveness of each policy in precluding the nonlinearity that may exacerbate economic downturn. In the second application, we take a longer-term perspective by analyzing trade-offs from dealing with financial stability issues with the help of macroprudential regulations. The finding may assist policymakers in striking the right balance between achieving growth and financial stability. We, lastly, show that active fiscal policy can greatly support the economy at times monetary policy is under constraint. All the applications, therefore, have shown potential gains from policy complementarity.

While our model serves a unified, analytical framework to analyze policy integration, which can be a useful starting point to enable a more consistent policy decision-makings, we believe that the IPF still needs to be enhanced in several other ways to reap its full benefits. Conceptually, we like to build a model that tells us, given our policy toolkit, the optimal integrated policy, completed with timings and magnitudes of each tool. We, therefore, intend to improve the current model along this dimension. Setting that aside, there are some limitations of the model that can be improved upon. On the analytical front, existing empirical work and country-specific experiences on the effectiveness and potential side-effects of the various policy tools can support any neglected part of the model and be useful in the policy decisions and calibration. For example, the model does not capture well the long-term, usually unwanted, consequences of policies.

On the practical front, the enhancement of IPF requires adjustments be made to the institutional arrangement governing the decision-making body and processes. In particular, decisions of different policies are usually made by different policy committees or departments within the central banks, or worse by different institutions, making policy integration a challenge. Integration between monetary policy and macroprudential regulations is often a case in point as an intra-institutional case for Thailand with two separate committees. The coordination between the central bank and the government, which may be necessary in crises for policy harmonization, may also make it harder for the central bank to remain shielded from political interference. Finally, the last piece of the IPF puzzle lies in the areas around communication, as a credible and transparent central bank can enact policies with much greater effectiveness. It is, therefore, prudent for central banks to engage with the public, inform them of the available policy toolkit, along with limitations and trade-offs of each policy tool, in order to manage their expectations and steer the economy forward. An analytical tool such as this model can also help with these efforts to increase the public's understanding by quantitatively illustrate results of implementing different combinations of tools.

# References

Adler, G. and Mano, R. (2016). The cost of foreign exchange intervention: Concepts and measurement. *IMF Working Papers*, 2016(89).

Adrian, T., Boyarchenko, N., and Giannone, D. (2019). Vulnerable growth. *American Economic Review*, 109(4):1263–89.

Adrian, T., Duarte, F., Liang, N., and Zabczyk, P. (2020a). Monetary and macroprudential policy with endogenous risk. *IMF Working Papers*, 2020(236).

Adrian, T., Erceg, C., Linde, J., Zabczyk, P., and Zhou, J. (2020b). A quantitative model for the integrated policy framework. *IMF Working Papers*, 2020(122).

Agénor, P.-R., Alper, K., and Pereira da Silva, L. (2012). Sudden floods, macroprudential regulation and stability in an open economy. *Journal of International Money and Finance*, 48.

Aikman, D., Bluwstein, K., and Karmakar, S. (2021). A tail of three occasionally-binding constraints: a modelling approach to GDP-at-Risk. *Bank of England Research Paper Series*.

Baksa, D., Bulíř, A., Heng, D., and Funke, N. (2020). A simple macrofiscal model for policy analysis: An application to Cambodia. *IMF Working Papers*, 2020(202).

Basu, S., Boz, E., Gopinath, G., Roch, F., and Unsal, F. (2020). A conceptual model for the integrated policy framework. *IMF Working Papers*, 2020(121).

Benes, J., Clinton, K., George, A., Gupta, P., John, J., Kamenik, O., Laxton, D., Mitra, P., Nadhanael, G., Portillo, R. A., Wang, H., and Zhang, F. (2017). Quarterly Projection Model for India; Key Elements and Properties. IMF Working Papers 2017/033, International Monetary Fund.

Berg, A., Karam, P. D., and Laxton, D. (2006). A practical model-based approach to monetary policy analysis–overview. *IMF Working Papers*, 2006(80).

Bernanke, B. S., Gertler, M., and Gilchrist, S. (1999). Chapter 21 the financial accelerator in a quantitative business cycle framework. In *Handbook of Macroeconomics*, volume 1, pages 1341 – 1393. Elsevier.

Blanchard, O. (2019). Public debt and low interest rates. *American Economic Review*, 109(4):1197–1229.

Borio, C. (2016). Revisiting three intellectual pillars of monetary policy. *Cato J.*, 36:213–238.

Borio, C. (2019). Macroprudential frameworks: experience, prospects and a way forward. In for International Settlements, B., editor, *Are post-crisis statistical initiatives completed?*, volume 49 of *IFC Bulletins chapters*. Bank for International Settlements.

Borio, C. and Disyatat, P. (2021). Integrated policy frameworks: The constraints of policy horizons and adjustment frequencies. SUERF Policy Note 246, The European Money and Finance Forum.

Borio, C., Drehmann, M., and Tsatsaronis, K. (2014). Stress-testing macro stress testing: does it live up to expectations? *Journal of Financial Stability*, 12:3–15.

Cecchetti, S., Mohanty, M., and Zampolli, F. (2011). The real effects of debt. BIS Working Papers 352, Bank for International Settlements.

Chung, H., Laforte, J.-P., Reifschneider, D., and William, J. C. (2012). Have we underestimated the likelihood and severity of zero lower bound events? *Journal of Money, Credit and Banking*, 44(s1):47–82.

Drehmann, M. (2006). Non-linearities and stress testing. In *Risk measurement and systemic risk, Proceedings of the fourth joint central bank research conference, ECB.*

Drehmann, M., Borio, C., and Tsatsaronis, K. (2012). Characterising the financial cycle: don't lose sight of the medium term! BIS Working Papers 380, Bank for International Settlements.

Eggertsson, G. and Woodford, M. (2003). The zero bound on interest rates and optimal monetary policy. In *Brookings Papers on Economic Activity*, volume 1, pages 139–233.

Ehrenbergerova, D. and Malovana, S. (2019). Introducing macro-financial variables into a semi-structural model. Working papers, Czech National Bank.

Filardo, A. and Rungcharoenkitkul, P. (2016). A quantitative case for leaning against the wind. BIS Working Papers 594, Bank for International Settlements.

Gertler, M. and Kiyotaki, N. (2010). Financial intermediation and credit policy in business cycle analysis. *Handbook of Monetary Economics*, 3:547–599.

Ghosh, A., Ostry, J., and Chamon, M. (2015). Two targets, two instruments: Monetary and exchange rate policies in emerging market economies. *Journal of International Money and Finance*, 12/01.

Hirakata, N., Kan, K., Kanafuji, A., Kido, Y., Kishaba, Y., Murakoshi, T., Shinohara, T., et al. (2019). The quarterly japanese economic model (Q-JEM): 2019 version. Technical report, Bank of Japan Tokyo.

Hofmann, B., Lombardi, M. J., Mojon, B., and Orphanides, A. (2021). Fiscal and monetary policy interactions in a low interest rate world. *Bank for International Settlements.*

Kiyotaki, N. and Moore, J. (1997). Credit Cycles. *Journal of Political Economy*, 105(2):211–248.

Lepetyuk, V., Maliar, L., and Maliar, S. (2017). Should Central Banks Worry About Nonlinearities of their Large-Scale Macroeconomic Models? Staff Working Papers 17-21, Bank of Canada.

Mohaddes, K., Raissi, M., and Weber, A. (2017). Can Italy grow out of its npl overhang? a panel threshold analysis. *Economics letters*, 159:185–189.

Montoro, C. and Ortiz, M. (2020). The Portfolio Channel of Capital Flows and Foreign Exchange Intervention in A Small Open Economy. Working Papers 168, Peruvian Economic Association.

Nualsri, A., Roengpitya, R., Sabborriboon, W., and Thanavibul, N. (2014). Forecasting the quality of corporate and consumer loans in the Thai banking sector: Methodology and policy implications. Working papers, Bank of Thailand.

Pongsaparn, R. (2008). A small semi-structural model for Thailand: Construction and applications. Working papers, Bank of Thailand.

Prasad, A., Elekdağ, S., Jeasakul, P., Lafarguette, R., Alter, A., Feng, A. X., and Wang, C. (2019). Growth at risk: Concept and application in IMF country surveillance. *Econometric Modeling: Macroeconomics eJournal*.

Ratanavararak, L., Ananchotikul, N., et al. (2018). Bank profitability and risk-taking in a low interest rate environment: The case of Thailand. *Puey Ungphakorn Institute for Economic Research Discussion Paper*, 89.

Rubio, M. and Carrasco-Gallego, J. (2014). Macroprudential and monetary policies: Implications for financial stability and welfare. *Journal of Banking & Finance*, 49.

Unsal, D. F. (2013). Capital Flows and Financial Stability: Monetary Policy and Macroprudential Responses. *International Journal of Central Banking*, 9(1):233–285.

Wongwachara, W., Jindarak, B., Nookhwun, N., Tunyavetchakit, S., and Klungjaturavet, C. (2018). Integrating Monetary Policy and Financial Stability: A New Framework. PIER Discussion Papers 100, Puey Ungphakorn Institute for Economic Research.

# Appendix

## A Computation of FX Intervention Cost

The concept of FX intervention costs, shown here, coincides with the ex-post costs in the work of Adler and Mano (2016). The authors show that, for a set of 73 emerging and advanced economies, ex-post costs have been large thanks to sizeable deviations from uncovered interest rate parity and the elevated central bank FX positions. Losses ($loss_t$) consist of two parts:

$$loss_t = \frac{\sum_{i=0}^{3}(loss_{t-i}^{idiff} + loss_{t-i}^{valuation})}{\sum_{i=0}^{3} yn_{t-i}}. \tag{A1}$$

The first of them is book costs ($loss_t^{idiff}$), which arise from the need for sterilization. The book costs measure the actual amount of interest payments arising from the increased central bank liabilities (net of interest revenue from holding international reserve assets):

$$loss_t^{idiff} = \frac{1}{400}(i_t - i_t^{us}) * reserve_t * s_t^{usdthb}. \tag{A2}$$

We use the differential between policy rates of Thailand and the U.S. as a proxy for such net costs. To compute the U.S. policy rate internally, we assume a constant wedge $\omega$ between global and U.S. policy rates:

$$i_t^{us} = i_t^* - \omega \tag{A3}$$

This is because Thailand's trading partner composition includes countries with interest rates fundamentally higher than the U.S. such as China and Indonesia. The second part is the valuation costs or gains ($loss_t^{valuation}$) that arise from the conversion of foreign assets into the domestic currency:

$$loss_t^{valuation} = reserve_{t-1} * \frac{\Delta s_t^{usdthb}}{4}, \tag{A4}$$

where $\Delta s_t^{usdthb} \simeq \Delta s_t$. In particular, an appreciation of the Thai baht induces an 'accounting' loss to the central bank's balance sheet. Since US dollar-based assets constitute the largest portion of Thailand's reserve assets, we use changes in the USD/THB exchange rate as the main determinant of this valuation effect. This second part constitutes the large variations in gains and losses from FX intervention. The evolution of foreign exchange reserves ($reserve_t$) is as follow:

$$reserve_t = reserve_{t-1} + \frac{1}{100} fxi_t \frac{yn_t}{s_t^{usdthb}} + \epsilon_t^{reserve}. \tag{A5}$$

We acknowledge that there are a few notable limitations by calculating the costs of foreign exchange intervention this way. First, our reserve assets are diversified both in terms of asset classes and currencies. Using USD/THB currency returns and the U.S. policy rate can only be considered a very rough approximation of their returns. Even domestic liabilities are more nuanced in that the Bank of Thailand can issue different maturities of BOT bonds, which can deviate from the policy rate. In addition, the model does not pay attention to some other consequences of intervention; we touched on the subject of being labeled a currency manipulator by U.S. authorities, but there are also benefits such as the lower country risk premium from holding sufficient foreign reserves.

## B Alternative Measure of Financial Stability Risks

As an alternative measure of overall financial stability risks, we introduce the concept of financial cycles and GDP at risk, which are readily available within the model. Financial cycles capture low-frequency booms and busts of financial variables, and have been proven a useful measure of financial imbalances and a predictor of financial crises. The seminal work of Drehmann et al. (2012) suggests applying a Christiano-Fitzgerald filter to financial variables of interest in order to extract their cyclical components. The length of cycles is prescribed at 8 to 30 years, making them less susceptible to short-term fluctuations. As an alternative measure of financial stability risks, we compute financial cycles as an arithmetic average of credit and property price cycles. Note that financial cycles, monitored by the Bank of Thailand, slightly differ from ones filtered from this model, since the former constructs 'financial cycle composite index' by applying the same filter to a total of eight financial variables[33], including both credit and asset price variables. Since we do not model the eight sub-components in this model, this version of the financial cycle is as follows:

$$fc_t = \frac{1}{2} cycle_t^{cred} + \frac{1}{2} cycle_t^{hp}. \quad \text{(B1)}$$

The upturn of financial cycles implies an accumulation of financial imbalances, which, if excessive, may unwind into a financial crisis. Hence, a large value of financial cycles means high risks to economic growth and a higher prospect of crises. So as to map such measure of financial imbalances into risks to growth, we use the reduced-form concept of growth-at-risk (GaR). Of interest to us is economic growth at the tail, say the lower 5th percentile, of the entire growth distribution. See more detail about GaR in Adrian et al. (2019) and the Bank of Thailand's monetary policy report box: The concept of growth at risk and the linkage to Thailand's financial stability, September 2019. The GaR measure in our model follows a simple, reduced-form equation, where the estimates come from Wongwachara et al. (2018), which rely on quantile regression for a panel of 9

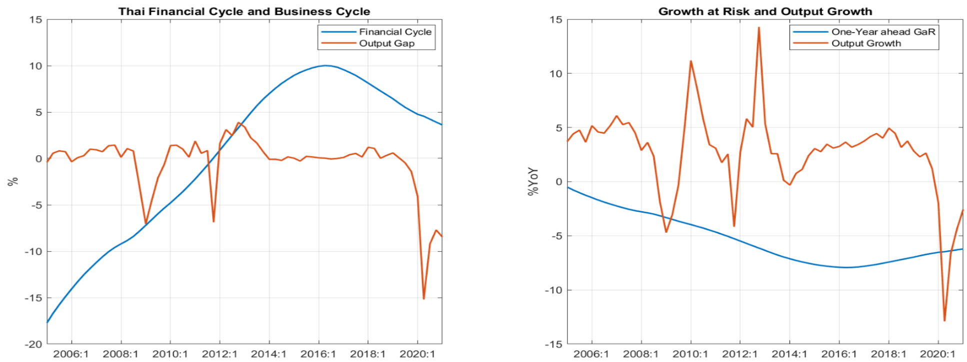
[33] The credit components includes (1) Nonfinancial corporates credit, (2) Non-financial corporates' credit to GDP, (3) household credit, and (4) household's credit to GDP. The asset price components include (1) house prices, (2) townhouse prices, (3) land prices, and (4) condominium prices

countries, both emerging and advanced, over the period 1993Q1-2017Q4:

$$GaR_{t+4} = -5.25 - 0.27 fc_t. \tag{B2}$$

The two measures outlined above provide us with alternative metrics to assess overall macro-financial risks within the economy. Figure B1 visualizes financial cycles and growth at risk produced by our model. The left panel depicts both financial and business cycles. We observe that the duration and amplitude of the former are considerably higher than those of the latter, suggesting a gradual buildup of financial vulnerabilities. Recent data show that financial cycles are at a high level, posing concerns over financial instability and worsening economic growth at risk. On the right panel, GaR well predicts the magnitude of economic recessions in 2008.

Figure B1: Financial Cycle and Growth at Risk




Note: All curves are filtered from the model using actual data from 1993Q1-2020Q1.

# C Measurement Variables

| Name | Description | Source |
|---|---|---|
| *Foreign variables* | | |
| $y_t^*$ | Weighted-average real GDP of Thailand's major trading partners (sa) | CEIC |
| $\pi_t^*$ | Weighted-average inflation of Thailand's major trading partners (%QoQsa) | CEIC |
| $i_t^*$ | Weighted-average policy rate of Thailand's major trading partners | CEIC |
| $\pi_t^{en,*}$ | Dubai crude oil prices (%QoQ) | CEIC |
| *Domestic variables* | | |
| $y_t$ | Thai gross domestic product, chain volume measures (sa) | NESDC |
| $\pi_t^{cpi}$ | Thai consumer price index (%QoQsa) | Ministry of Commerce |
| $\pi_t^{rf}$ | Raw food price sub-index of Thai CPI (%QoQsa) | Ministry of Commerce |
| $\pi_t^{en}$ | Energy price sub-index of Thai CPI (%QoQsa) | Ministry of Commerce |
| $\pi_t$ | Thai CPI sub-index used for calculation of core inflation index (%QoQsa) | Ministry of Commerce |
| $s_t$ | Nominal effective exchange rate of Thai baht | Bank of Thailand |
| $i_t$ | 1-day bilateral repurchase rate | Bank of Thailand |
| $ca_t$ | The ratio of current account balance to nominal GDP measured in USD (sa) | Bank of Thailand |
| $pdeficit_t$ | The ratio of nominal primary deficit to nominal GDP (%) | Bank of Thailand |
| $deficit_t$ | The ratio of nominal debt service to Nominal GDP (%) | Public Debt Management Office |
| $debt_t$ | The ratio of nominal public debt to nominal GDP (%) | Public Debt Management Office |
| *Macro-financial variables* | | |
| $cred_t$ | Private credit to households and non-financial corporates, including both loans and debt securities | Bank of Thailand |
| $hp_t$ | Property prices (average of land, condominium, townhouse and single-detached house prices) | Bank of Thailand |
| $npl_t$ | Non-performing and special-mention loan outstanding of commercial banks | Bank of Thailand |
| $TP_t^{2y}$,$TP_t^{5y}$ | 2y and 5y term premiums, proxied by the difference between 2y and 5y government bond yields and the policy rate | Bloomberg |
| $ilend_t^{2y}$ | New loans rate (NLR) | Bank of Thailand |
| $fxi_t$ | Foreign exchange intervention as proxied by ratio of balance of payment to quarterly real GDP | Bank of Thailand |
| $pflows_t$ | Portfolio flow to quarterly real GDP | Bank of Thailand |

# D Prior and Posterior Distribution

| Parameter | Description | Distr. | Prior Mean | Prior SD | Posterior Mode | Posterior SD |
|---|---|---|---|---|---|---|
| IS equation | | | | | | |
| $\theta_{y,b}$ | Output gap persistence | beta | 0.45 | 0.05 | 0.45 | 0.0017 |
| $\theta_{y,f}$ | Impact of expected output gap | beta | 0.1 | 0.05 | 0.1641 | 0.0010 |
| $\beta_r$ | Impact of real interest rate gap | gamma | 0.03 | 0.03 | 0.0105 | 0.0372 |
| $\beta_z$ | Impact of real exchange rate gap | gamma | 0.05 | 0.02 | 0.0478 | 0.0004 |
| $\beta_{y^*}$ | Impact of foreign output gap | gamma | 0.25 | 0.1926 | 0.5 | 0.0022 |
| $\beta_{cred}$ | Impact of credit growth | gamma | 0.2 | 0.01 | 0.1935 | 0.0001 |
| $\beta_{npl}$ | Impact of NPL gap | gamma | 0.15 | 0.05 | 0.1 | 0.0004 |
| $\beta_{pdeficit}$ | Impact of primary deficit | gamma | 0.9 | 0.5 | 0.9135 | 0.3645 |
| PC equation | | | | | | |
| $\theta_{\pi,b}$ | Inflation persistence | gamma | 0.75 | 0.02 | 0.7 | 0.0003 |
| $\theta_{\pi,f}$ | Impact of expected inflation | gamma | 0.3 | 0.05 | 0.3 | 0.0012 |
| $\alpha_y$ | Impact of output gap | gamma | 0.05 | 0.01 | 0.0576 | 0.0001 |
| $\kappa^*$ | Export content | gamma | 0.05 | 0.01 | 0.2800 | 0.0242 |
| $\alpha_{\Delta y}$ | Impact of change in output gap | gamma | 0.2 | 0.05 | 0.1648 | 0.0001 |
| $\alpha_{\pi^m}$ | Impact of import price inflation | gamma | 0.05 | 0.05 | 0.01 | 0.0001 |
| $\alpha_z$ | Impact of real exchange rate gap | gamma | 0.01 | 0.005 | 0.0161 | 0.0000 |
| $\alpha_{\pi^{rf}}$ | Impact of raw food inflation | gamma | 0.005 | 0.0081 | 0.5 | 0.0000 |
| $\alpha_{\pi^{en}}$ | Impact of energy inflation | gamma | 0.015 | 0.0131 | 0.5 | 0.0000 |
| Monetary policy rule | | | | | | |
| $\rho_i$ | Policy rate persistence | beta | 0.5 | 0.1 | 0.8819 | 0.0008 |
| $\phi_y$ | Response to output gap | gamma | 1.0 | 0.1 | 1.0466 | 0.0055 |
| $\phi_\pi$ | Response to inflation deviation from target | gamma | 1.5 | 0.2 | 1.5678 | 0.0335 |
| Primary deficit equation | | | | | | |
| $\rho_{pdeficit}$ | Primary deficit persistence | beta | 0.25 | 0.1 | 0.2783 | 0.0139 |
| $\phi_y^g$ | Response to output gap | gamma | 0.05 | 0.025 | 0.0187 | 0.0000 |
| $\phi_{debt}^g$ | Response to debt/GDP deviation from target | gamma | 0.05 | 0.025 | 0.0105 | 0.0000 |
| Credit growth equation | | | | | | |
| $\rho_{cred}$ | Credit growth persistence | beta | 0.3 | 0.1 | 0.5738 | 0.0075 |
| $\theta_{rlend,2y}^{cred}$ | Impact of 2y real lending rate gap | gamma | 0.3 | 0.1 | 0.2326 | 0.0015 |
| $\theta_{rlend,5y}^{cred}$ | Impact of 5y real lending rate gap | gamma | 0.2 | 0.1 | 0.1999 | 0.0368 |
| $\theta_y^{cred}$ | Impact of output gap | gamma | 0.4 | 0.1 | 0.3055 | 0.0089 |
| $\theta_{hp}^{cred}$ | Impact of property price growth | gamma | 0.5 | 0.1 | 0.5 | 0.0045 |
| Property price growth equation | | | | | | |
| $\rho_{hp}$ | Property price growth persistence | beta | 0.3 | 0.1 | 0.4090 | 0.0094 |
| $\theta_{cred}^{hp}$ | Impact of credit growth | gamma | 0.5 | 0.1 | 0.4674 | 0.0095 |
| $\theta_r^{hp}$ | Impact of real interest rate gap | gamma | 0.4 | 0.1 | 0.3994 | 0.0087 |
| $\theta_y^{hp}$ | Impact of output gap | gamma | 0.3 | 0.1 | 0.4186 | 0.0087 |
| Non-performing loan equation | | | | | | |
| $\rho_{npl}$ | NPL gap persistence | beta | 0.7 | 0.1 | 0.7324 | 0.0020 |
| $\theta_y^{npl}$ | Impact of past output gap | gamma | 0.4 | 0.1 | 0.4429 | 0.0080 |
| $\theta_{cred}^{npl}$ | Impact of past credit growth | gamma | 0.3 | 0.1 | 0.2181 | 0.0068 |
| $\theta_{rlend,2y}^{npl}$ | Impact of real lending rate gap | gamma | 0.2 | 0.1 | 0.1631 | 0.0241 |

| Parameter | Description | Distr. | Prior Mean | Prior SD | Posterior Mode | Posterior SD |
|---|---|---|---|---|---|---|
| Lending rate equations | | | | | | |
| $\rho_{ilend,2y}$ | Persistence of 2y nominal lending rate | beta | 0.7 | 0.1 | 0.7488 | 0.0073 |
| $\rho_{ilend,5y}$ | Persistence of 5y nominal lending rate | beta | 0.7 | 0.1 | 0.7488 | 0.0073 |
| $\rho_{tp,2y}$ | Persistence of 2y term premium | beta | 0.5 | 0.1 | 0.5614 | 0.0054 |
| $\rho_{tp,5y}$ | Persistence of 5y term premium | beta | 0.5 | 0.1 | 0.4182 | 0.0001 |
| $\rho_{cp}$ | Persistence of credit risk premium | beta | 0.6 | 0.1 | 0.6492 | 0.0075 |
| $\theta^{cp}_{npl}$ | Sensitivity of credit risk premium to NPL | gamma | 0.25 | 0.05 | 0.13 | 0.0004 |
| $\theta_{debt}$ | Sensitivity of term premium to public debt deviation | gamma | 0.01 | 0.005 | 0.0075 | 0.0000 |
| Foreign IS equation | | | | | | |
| $\theta^*_{y,b}$ | Foreign output gap persistence | beta | 0.5 | 0.25 | 0.6775 | 0.0020 |
| $\theta^*_{y,f}$ | Impact of expected foreign output gap | beta | 0.25 | 0.05 | 0.1823 | 0.0019 |
| $\beta_{r^*}$ | Impact of foreign interest rate gap | gamma | 0.1 | 0.03 | 0.1572 | 0.0014 |
| Foreign PC equation | | | | | | |
| $\theta^*_{\pi,b}$ | Foreign inflation persistence | beta | 0.5 | 0.1 | 0.1821 | 0.0017 |
| $\theta^*_{\pi,f}$ | Impact of expected foreign inflation | beta | 0.2 | 0.05 | 0.2746 | 0.0009 |
| $\alpha^*_y$ | Impact of foreign output gap | gamma | 0.3 | 0.1 | 0.1617 | 0.0071 |
| $\alpha^*_{\pi^{en}}$ | Impact of global oil price | gamma | 0.2 | 0.05 | 0.0150 | 0.0000 |
| Foreign monetary policy rule | | | | | | |
| $\rho_{i^*}$ | Foreign policy rate persistence | beta | 0.5 | 0.1 | 0.8163 | 0.0012 |
| $\phi_{y^*}$ | Response to foreign output gap | gamma | 0.7 | 0.1 | 0.3995 | 0.0066 |
| $\phi_{\pi^*}$ | Response to foreign inflation deviation from target | gamma | 1.5 | 0.2 | 0.9895 | 0.297 |
| Global oil price equation | | | | | | |
| $\rho_{\pi^{en,*}}$ | Global oil price persistence | beta | 0.5 | 0.1 | 0.2708 | 0.0015 |
| $\eta^*$ | Impact of global output gap | gamma | 0.5 | 0.1 | 0.5178 | 0.0128 |
| Energy inflation equation | | | | | | |
| $\rho_{\pi^{en}}$ | Energy inflation persistence | beta | 0.2 | 0.05 | 0.3 | 0.0011 |
| $\gamma_{\pi^{en}}$ | Impact of global oil price | gamma | 0.5 | 0.15 | 0.1 | 0.0005 |
| UIP condition | | | | | | |
| $\rho_s$ | Exchange rate persistence | beta | 0.5 | 0.35 | 0.3 | 0.0013 |
| $\gamma_{ca}$ | Impact of current account gap | gamma | 0.05 | 0.01 | 0.04 | 0.0002 |
| $\gamma_{FXI}$ | Impact of FX intervention | gamma | 0.2 | 0.05 | 0.1421 | 0.0007 |
| $\gamma_{portflows}$ | Impact of portfolio flow | gamma | 0.1 | 0.05 | 0.1337 | 0.0013 |
| Current account equation | | | | | | |
| $\rho_{ca}$ | Current account gap persistence | beta | 0.75 | 0.05 | 0.75 | 0.1 |
| $\theta^{ca}_z$ | Impact of real exchange rate gap | gamma | 0.1 | 0.05 | 0.08 | 0.1 |
| $\theta^{ca}_y$ | Impact of output gap | gamma | 0.5 | 0.1 | 0.1 | 0.1 |
| $\theta^{ca}_{y^*}$ | Impact of foreign output gap | gamma | 0.6 | 0.1 | 0.7513 | 0.1 |
| FX intervention rule | | | | | | |
| $\omega_s$ | Response to change in nominal exchange rate | gamma | 0.2 | 0.05 | 0.2149 | 0.0036 |
| $\omega_z$ | Response to real exchange rate gap | gamma | 0.05 | 0.02 | 0.01 | 0.0005 |
| Portfolio flow equation | | | | | | |
| $\rho_{portflows}$ | Portfolio flow persistence | beta | 0.2 | 0.05 | 0.1337 | 0.0027 |
| $\omega_p$ | Impact of interest rate differential | gamma | 0.1 | 0.05 | 0.1635 | 0.0040 |
| Risk premium equation | | | | | | |
| $\gamma_{debt}$ | Impact of public debt deviation | gamma | 0.01 | 0.005 | 0.0075 | 0.0000 |

| Parameter | Description | Distr. | Prior Mean | Prior SD | Posterior Mode | Posterior SD |
|---|---|---|---|---|---|---|
| Trend persistence | | | | | | |
| $\rho_{\Delta\bar{y}}$ | Persistence in Thai potential output growth | beta | 0.6 | 0.2 | 0.8913 | 0.0052 |
| $\rho_{\bar{r}}$ | Persistence in Thai neutral real interest rate | beta | 0.5 | 0.1 | 0.5414 | 0.0085 |
| $\rho_{\Delta\bar{z}}$ | Persistence in equilibrium real exchange rate growth | beta | 0.75 | 0.05 | 0.6104 | 0.0029 |
| $\rho_{\Delta\bar{npl}}$ | Persistence in NPL trend growth | beta | 0.8 | 0.1 | 0.8974 | 0.0011 |
| $\rho_{\bar{rlend},2y}$ | Persistence of 2y neutral real lending rate | beta | 0.8 | 0.1 | 0.8152 | 0.0057 |
| $\rho_{\bar{rlend},5y}$ | Persistence of 5y neutral real lending rate | beta | 0.8 | 0.1 | 0.8375 | 0.0040 |
| $\rho_{\bar{ca}}$ | Persistence in current account trend | beta | 0.8 | 0.05 | 0.7407 | 0.0032 |
| $\rho_{\Delta\bar{y}^*}$ | Persistence in foreign potential output growth | gamma | 0.5 | 0.1 | 0.7790 | 0.0059 |
| $\rho_{\bar{r}^*}$ | Persistence in foreign neutral real interest rate | beta | 0.8 | 0.1 | 0.7459 | 0.0071 |
| Variance of shocks | | | | | | |
| $\epsilon_t^{y^*}$ | Shock to foreign output gap | inv.gamma | 0.7 | 0.7 | 0.5071 | 0.0028 |
| $\epsilon_t^{\pi^*}$ | Shock to foreign inflation | inv.gamma | 0.5 | 0.1 | 0.8525 | 0.0055 |
| $\epsilon_t^{\pi^{en,*}}$ | Shock to global oil price | inv.gamma | 40 | 5 | 46.5848 | 4.9163 |
| $\epsilon_t^{i^*}$ | Shock to foreign policy rate | inv.gamma | 0.7 | 0.2 | 0.3779 | 0.0025 |
| $\epsilon_t^{y}$ | Shock to output gap | inv.gamma | 1 | 0.3 | 1.643 | 0.0148 |
| $\epsilon_t^{\pi}$ | Shock to core inflation | inv.gamma | 0.5 | 0.1 | 0.9731 | 0.0034 |
| $\epsilon_t^{rf}$ | Shock to raw food inflation | inv.gamma | 3 | 1 | 8.0249 | 0.2656 |
| $\epsilon_t^{en}$ | Shock to energy inflation | inv.gamma | 12 | 2 | 12.1596 | 0.8364 |
| $\epsilon_t^{i}$ | Shock to policy rate | inv.gamma | 0.3 | 0.05 | 0.3718 | 0.0010 |
| $\epsilon_t^{s}$ | Shock to nominal exchange rate | normal | 2 | 0.5 | 2.0531 | 0.0313 |
| $\epsilon_t^{ca}$ | Shock to current account gap | inv.gamma | 2.25 | 1 | 3.4627 | 0.0697 |
| $\epsilon_t^{cred}$ | Shock to credit growth | inv.gamma | 2.5 | 0.5 | 3.7545 | 0.0821 |
| $\epsilon_t^{hp}$ | Shock to property price growth | inv.gamma | 5 | 1 | 7.1492 | 0.5781 |
| $\epsilon_t^{npl}$ | Shock to NPL gap | inv.gamma | 8 | 2 | 5.4046 | 0.4250 |
| $\epsilon_t^{TP,2y}$ | Shock to 2y term premium | inv.gamma | 0.5 | 0.25 | 0.4473 | 0.0010 |
| $\epsilon_t^{TP,5y}$ | Shock to 5y term premium | inv.gamma | 0.5 | 0.25 | 0.4473 | 0.0010 |
| $\epsilon_t^{CP}$ | Shock to credit risk premium | inv.gamma | 0.25 | 0.1 | 0.5838 | 0.0014 |
| $\epsilon_t^{pdeficit}$ | Shock to primary deficit | inv.gamma | 0.5 | 0.25 | 0.0588 | 0.0000 |
| $\epsilon_t^{debt}$ | Shock to public debt | inv.gamma | 1.5 | 0.25 | 1.2087 | 0.0254 |
| $\epsilon_t^{debtservice}$ | Shock to public debt service | inv.gamma | 0.1 | 0.05 | 0.01 | 0.0000 |
| Variance of trend shocks | | | | | | |
| $\epsilon_t^{\Delta\bar{y}}$ | Shock to potential output growth | inv.gamma | 0.6 | 0.05 | 0.6 | 0.0030 |
| $\epsilon_t^{\bar{r}}$ | Shock to neutral real interest rate | inv.gamma | 0.5 | 0.05 | 0.7659 | 0.0028 |
| $\epsilon_t^{\bar{ca}}$ | Shock to currrent account trend | inv.gamma | 0.8 | 0.05 | 0.6719 | 0.0156 |
| $\epsilon_t^{\Delta\bar{z}}$ | Shock to equilibrium real exchange rate growth | inv.gamma | 1 | 0.25 | 1.0773 | 0.0252 |
| $\epsilon_t^{premium}$ | Shock to risk premium | inv.gamma | 0.5 | 0.1 | 0.5948 | 0.0131 |
| $\epsilon_t^{\Delta\bar{npl}}$ | Shock to change in NPLs trend | inv.gamma | 0.5 | 0.1 | 1.4289 | 0.0474 |
| $\epsilon_t^{\Delta\bar{y}^*}$ | Shock to foreign potential output growth | inv.gamma | 0.2 | 0.05 | 0.4209 | 0.0056 |
| $\epsilon_t^{\bar{r}^*}$ | Shock to foreign neutral real interest rate | inv.gamma | 0.2 | 0.05 | 0.5277 | 0.0070 |
| $\epsilon_t^{\bar{rlend},2y}$ | Shock to 2Y neutral real lending rate | inv.gamma | 0.2 | 0.1 | 0.2257 | 0.0054 |
| $\epsilon_t^{\bar{rlend},5y}$ | Shock to 5Y neutral real lending rate | inv.gamma | 0.5 | 0.01 | 0.7573 | 0.0001 |

# E Nonlinearity

Here we plot the six nonlinear functions described in Section 3.3.

Figure E1: Plots of the Model's Nonlinear Functions